SpecX – A Linux Software Suite for Electrical and Computer Engineering Education

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ABSTRACT The undergraduate program in Electrical and Computer Engineering (ECE) requires extensive use of tools within its 3 to 4-year curriculum. These tools are accessible to students at the University, where students spend several hours completing their assignments, which is often hard. Hence, students (sadly) often resort to either using pirated software or copying their colleagues' work. To facilitate experimental learning, the authors have coupled Linux-based tools free for academic use, all together as an easy-to-use, GUI package that enables an automatic installation and configuration of 207 tools catering to the entire ECE undergraduate program. The developed solution, SpecX, provides instant relief to students and teachers engaged in ECE education globally.

INDEX TERMS circuits and systems, computer networks, communication systems, control systems, documentation, Linux.

I. INTRODUCTION

Engineering courses are heavy on lab work, and Electrical and Computer Engineering (ECE) is no different. Several online platforms, such as Khan Academy, MIT Open Courseware (MIT-OCW), Udemy, Coursera, and edX provide courses, online lectures, assignments, exams, and solutions for a broad range of topics [1]. Universities, too, provide course material online.

For engineering education, these efforts do well for engaging the visual and auditory faculties of students. However, the tactile and kinesthetic impressions are limited, primarily because engineering courses contain laboratory work [1]. The lab work requires resources and software packages that are often expensive.

Therefore, students either need to spend significant time in labs to complete their work, or access tools remotely (which is uncommon in third-world countries), or pay for expensive software themselves. Since most tools are costly, many students end up pirating software. Software piracy is especially high in countries where students cannot afford to buy software or where universities do not have 24-hour open labs. Interestingly, students in high-income countries also face similar challenges [2], [3]. Moreover, malware infections are tightly linked to using pirated and unlicensed software [1]. Additionally, sometimes the university does not have enough funds for the necessary set of tools, which may be exacerbated by USD or Euro exchange rates.

Therefore, to circumvent these challenges and facilitate ECE education, the authors provided a qualitative survey of free Computer Aided Design (CAD) tools available for ECE coursework, while filtering out tools published before 2010 (outdated) that are not free-to-use by academia, do not work offline, require an active internet connection, and are not Linux-based [4].

Even though the survey is helpful and

*Corresponding Author: bilalwajidabbas@hotmail.com informative for the faculty and students, from a practical standpoint, merely mentioning them alone does not help solve the current problem.

As these tools are Linux-based, their installation constitutes downloading, resolving necessary dependencies, and compiling. Managing and installing dependencies manually is not an easy task, as software may have many dependencies. To top it off, some dependencies can have their own dependencies (Dependency hell), frustrating some users.

Therefore, through this effort, the authors developed "SpecX," a Linux software solution designed to dispense instant relief to faculty and students in all four learning modalities (visuals: descriptions and pictures, auditory sensations: dialogues and discussions, tactile perceptions: labs and hands-on work, and kinesthetic impressions: movement) by providing free and easily accessible tools related to ECE. SpecX is designed to smooth the way for academic usage and distribution by taking care of copyright restrictions as it complies with the GNU Affero General Public License v3.0 (AGPL-3.0).

By making SpecX an integral part of ECE coursework, universities and institutions can significantly reduce the cost of software distribution and management. SpecX may be used by faculty to test students' learning via lab work, projects, and homework assignments, all within the framework of the same software package. All the software included in SpecX is categorized according to the general disciplines in the year ECE undergraduate curriculum, as shown in Tables I and II.

II. METHODOLOGY

To develop the software suite, the following process was employed:

- Survey courses offered in the ECE programs.
- Classify the above courses in broad subject categories.
- Investigate tools developed by the community to facilitate ECE education.
- Filter out tools published before 2010 (outdated) that are not free-to-use by academia, do not work offline, require an active internet connection, and are not Linux-based [5].
- Automate the entire installation process by using Linux bash scripting to develop automated installation frameworks for each of the selected tools.
- Resolve interdependencies of the selected tools by generating a shell file.
- Encapsulate the whole framework within a graphical user interface (GUI) to ease the installation process for the user.

III. RESULTS AND DISCUSSION

The authors conducted an extensive survey of courses offered in the ECE program and classified them into seven broad categories (Table I).

TABLE I

Yr.	ECE Curriculum Course	Category	Yr.	ECE Curriculum Course	Category
Freshman	Electric Circuit Theory	CPCB	Senior	Introduction to VLSI	CPCB
	Calculus	MN		Design	CPCB
	Differential Equations	MN		Electrical Instruments	CPCB
	Multivariate Calculus	MN		Integrated Electronic	CPCB
	Communication Skills	TWP		Circuits	CPCB/PS
	Computer Fundamentals	PROG		Industrial Electronics	PS
Sophomore	Semiconductor Devices	CPCB		Power Electronics	PS
	Digital System Design	CPCB		High Voltage	PS
	Analog and Digital	CPCB		Engineering	PS
	Circuits	COMM		Renewable Energy	PS
	Signals and Systems	MN		Systems	COMM
	Discrete	MN		Design of Electrical	COMM
	Mathematics/Structures	PROG		Machines	COMM
	Linear Algebra	PROG		Power System Protection	COMM
	Object Oriented	PROG		Introduction to Smart	COMM
	Programming	TWP		Grids	MN/PROG
	Programming	EMBD		Satellite Engineering	PROG
	Fundamentals	MN		Wireless	PROG
	Data Structures and			Communications	PROG
	Algorithms			Microwave Engineering	PROG
	Technical Writing and			Electromagnetic	PROG
	Presentation			Compatibility	EMBD
	Microprocessor Systems			Optical Circuits and	TWP
	Numerical Methods			Systems	TWP
Junior	Applied Probability and	MN		Digital Image Processing	
	Statistics	MN/EMBD		Database Engineering	
	Control Systems	MN/COMM		Introduction to Machine	
	Digital Signal Processing	COMM		Learning	
	Electromagnetic Theory	COMM		Computer Networks	
	Analog and Digital	COMM		Software Construction	
	Communications	EMBD		Artificial Intelligence	
	Antenna Systems	PROG		Computer Architecture	
	Introduction to Robotics	PS		Project Management	
	Operating Systems	PS		Thesis Writing	
	Power Transmission and	PS		(Capstone Project)	
	Distribution				
	Electric Machinery				
	Fundamentals				
	Power System Analysis				
	and Design				

TABLE II

Primary Category	Sub-category	Tools	Total
Mathematical and Numerical Analysis	Mathematical Analysis	GNU Octave, SageMath, Scilab, Gretl, GeoGebra, PSPP, SMathStudio, Tilp, OenEPI, Shogun [4].	10
	Finite Element Analysis	Agros2D, Calculix, CodeAster, DUNE, Elmer, F Enics Project, Free	18

Primary Category	Sub-category	Tools	Total
		Fem++, GiD, Get FEM++, Hermes Project, Julia FEM, MoFEM JosePH, OOFEM, Open FOAM, Range Software [4], Deal.II [6], MFEM [7].	
Programming	C/C++/C#	NetBeans C/C++ pack, Qt Creator, Eclipse IDE (C/C++), Kdevelop (C/C++), MonoDevelop [4], Code::Blocks [8], CodeLite [9], Ultimate++ the IDE [10], Anjuta [11].	8
	Java	BlueJ, NetBeans JAVA pack, Dr Java, Eclipse IDE (JAVA), Greenfoot, IntelliJ IDEA Com [4]	6
	Python	IDLE, PyCharm, Eric, KDevelop (Python), NINJA-IDE, Anaconda, Pyzo, Thonny [4].	8
	Ruby	Aptana Studio 3, NetBeans (Ruby) [4]	2
	Tcl/Tk	VTCL [4]	1
	Perl	NetBeans (Perl) [4]	1
	HTML/CSS/Javascript	Aptana Studio 3, Eclipse WTP, Sea Monkey, Amaya, KompoZer, BlueGriffon, NetBeans packs, Brackets [12]	8
	PHP	Eclipse PDT [4]	1
	DBMS	MySQL Workbench, phpMy Admin, Maria DB, SQLite, Percona Toolkit, DBVizualizer [4], Adminer [12], DBeaver [13]	8
	CLISP	Portacle, Lispbox, GNU Emacs (CLISP), SBCL, GNU Zile, Xemacs, Emacspeak [4]	7
	R	RStudio, RKWard, Sublime Text, Atom, Visual Studio Code, Vim, jEdit, Brackets, JED, GNU nano, GNU Emacs [4], Komodo Edit [14], Geany [15], BlueFish [16].	14
	Compilers	ActivePerl interpreter (Perl), python (Python), ActiveTcl (Tcl/Tk), ruby (Ruby), r-base, GCC GNAT (ADA), NASM (Intel *86), FreeBASIC (BASIC), GNU Compilers (C/C++), Mono (C#), GnuCOBOL (COBOL) [4], javac (JAVA) [17].	12
Circuit Analysis and PCB Design	PCB Design	FidoCadJ, Gerbv, Kicad [4]	3
	Protoboard Viewer	Fritzing [4]	1
	Circuit Simulator	gEDA [4], SimulIDE [18]	2

Primary Category	Sub-category	Tools	Total
	Integrated Synthesis Environment (ISE)	Icarus Verilog, HADES [4]	2
	VLSI	Electric, Magic VLSI [4]	2
	SPICE	Oregano, Ngspice, gspiceui, GNU-Cap, Gwave, GTKWave, QSapecNG, NetlistViewer [4]	8
	Power Systems	GridLAB-D, PyPSA, Penthode, RAPSim, Python Power Electronics [4]	5
Embedded Systems (EMBD)	PIC Tools	MPLAB, PICSimLab, Gputils [4], SDCC [19]	4
	ARM Tools	Code Composer Studio, Eclipse MCU [4]	2
	AVR Tools	Simuavr [4], AVR toolchain [20]	2
	8051 Tools	MCU 8051 IDE, GNU 8085 Simulator, SDCC [4]	3
	Texas Instruments Tools	Energia [4]	1
	RISC-V Tools	RISCV-VP, Eclipse MCU, Jupyter [4], RAR [21], Renode [22]	5
	MIPS Tools	MARS, Spim [4]	2
Networking (NET)	Network Design	Edraw [23]	1
	Network Simulation	Packet Tracer, Gns3, Wireshark, tcpdump [4]	4
	Network Monitoring	Zabbix [4], Icinga 2 [24]	2
Communication Systems (COMM)	Electromagnetism	gprMax, Angora [4]	2
	Antenna Design	Meep, openEMS, MaxFEM [4]	3
Technical Writing and Presentation Skills (TWP)	Documentation	TeX Live, TeXstudio, TeXmaker, Gummi, Lyx, GNU TeXmacs, Halibut	7
	Word Processor	LibreOffice Writer, WPS Office Writer, AbiWord, CalligraWords	4
	Spreadsheet Editor	LibreOffice calc, WPS Office Spreadsheets, Gnumeric, Pyspread, CalligraSheets	5
	Presentations	LibreOffice Impress, WPS Office Presentations, CalligraStage	3
	Diagram/Flowchart	LibreOffice Draw, Dia, yEd, Edraw Flowchart Software	4
	Citation tools	Zotero, JabRef, KBibTeX, Referencer	4
	Project Management	Git, GitKraken, TaskJuggler, Gantt Project	4
	Schematic Design	CircuiTikZ, XCircuit [4]	2
Utilities and Plugins	Virtual Machines	VirtualBox, QEMU [4]	2
	Other Virtualization	tty0tty, socat [4]	2
	Serial Monitor	PuTTY [4]	1
	Calculator	SpeedCrunch, Generic Mapping Tools, Qalculate, GNOME Calculator [4]	4

Primary Category	Sub-category	Tools	Total
	Unit Converter	Gonvert, ConvertAll, MultiConvert [4]	3
	Help & Learning	Golden Dict, Artha, Resistor Color Calculator, StarDict [4].	4
		Total tools in SpecX	207

Table enumerates a list of all courses offered in an ECE undergraduate program with their suggested categories, as defined by the authors. These are (i) Mathematical and Numerical Analysis (MN), (ii) Programming (PROG), (iii) Circuit Analysis and PCB Design (CPCB), (iv) Power Systems (PS), (v) Embedded Systems (EMBD), (vi) Communication Systems (COMM), and (vii) Technical Writing and Presentation (TWP).

Thereafter, the authors surveyed extensive 381 tools developed by the community to facilitate ECE education [4], and filtered out tools published before 2010 (outdated) that are not free-to-use by academia, do not work offline, require an active internet connection, and are not Linux-based, leaving 207 tools for SpecX, as shown in Tables II, and Figures 1 and 2.

The Table enumerates the 206 tools presented in SpecX. Extending the nomenclature in Table I, these tools are divided into seven categories highlighted above. All the tools published after 2010, available offline, are Linux-based and are free for academic use.

The authors employed Linux bash scripting [5] to facilitate installing each tool by including necessary dependencies to ensure users develop workstations quickly and easily. Hence, SpecX is designed by coupling together 207 shell executable files (with front-end GUI) to download and install software based on the user's needs. The shell files are listed below:

Superuser Access: As administrative privileges are needed to install, the first executable shell file obtains the 'sudo' (superuser) access from the user. The process terminates if the password is incorrect.

Internet Availability: Checks if the system has an active internet connection and terminates if the internet is unavailable.

Install/Uninstall Selection: Allows the user to proceed towards installation or uninstallation.

Dependencies Installation: Downloads and installs the dependencies of the selected software.

Mathematical and Numerical Analysis: Facilitates the user to automatically install tools related to (a) Mathematical Analysis and (b) Finite Element Analysis.

Programming: Automate the installation of tools based upon (a) C/C++, (b) CSS and Visual Basic (c) JAVA, (d) Ruby, (e) Tcl/Tk, (f) Perl, (g) HTML/CSS/Javascript (h) PHP, (i) DBMS, (j) CLISP and (k) R Development.

Circuit Analysis and PCB Design: Aids the setup of tools categorized in (a) Schematic and PCB Design, (b) Protoboard Viewer, (c) Schematic and Circuit Simulator, (d) Integrated Synthesis Environment (ISE), (e) Very-large-scale integration (VLSI), (f) Simulation Program with Integrated Circuit Emphasis (SPICE) and (g) Printable Schematic Design.

Power Systems: Facilitates the installation of tools classified under Power Systems.

Embedded Systems: Automate the installation of tools falling under categories of (a) PIC, (b) ARM, (c) Arduino, (d) AVR, (e) 8051, (f) Texas Instruments, (g) RISC-V, and (h) MIPS Development Tool.

Networking: Install tools classified under (a) Network Design, (b) Network Simulation, and (c) Network Monitoring.

Communication Systems: Automate the installation of tools based upon (a) Antenna Design and Simulation and (b) EM Simulation.

Technical Writing and Presentation: Facilitates the installation of tools based upon (a) Document Preparation System, (b) Word Processors, (c) Spreadsheet editors, (d) Presentation program, (e) Diagram/Flowchart, (f) Reference and Citation, and (g) Project management.

Utilities and Plugins: Automates the installation of tools classified under (a) Virtual Machines, (b) Other Virtualization, (c) Serial monitors, (d) Calculators, (e) Unit Converters, and (f) Help and Learning Resources.

The authors employed 'Zenity' and 'yad' for developing GTK+ dialogs [5] as the front-end GUI for users to make the process user-friendly, removing the hassle of the command-line interface, see Figure 3.

SpecX is available on Windows, macOS, and Linux. Specifically, SpecX caters to 75% of the Linux Community, see Section 5 titled "Availability and Requirements." SpecX currently supports ×64 architecture.

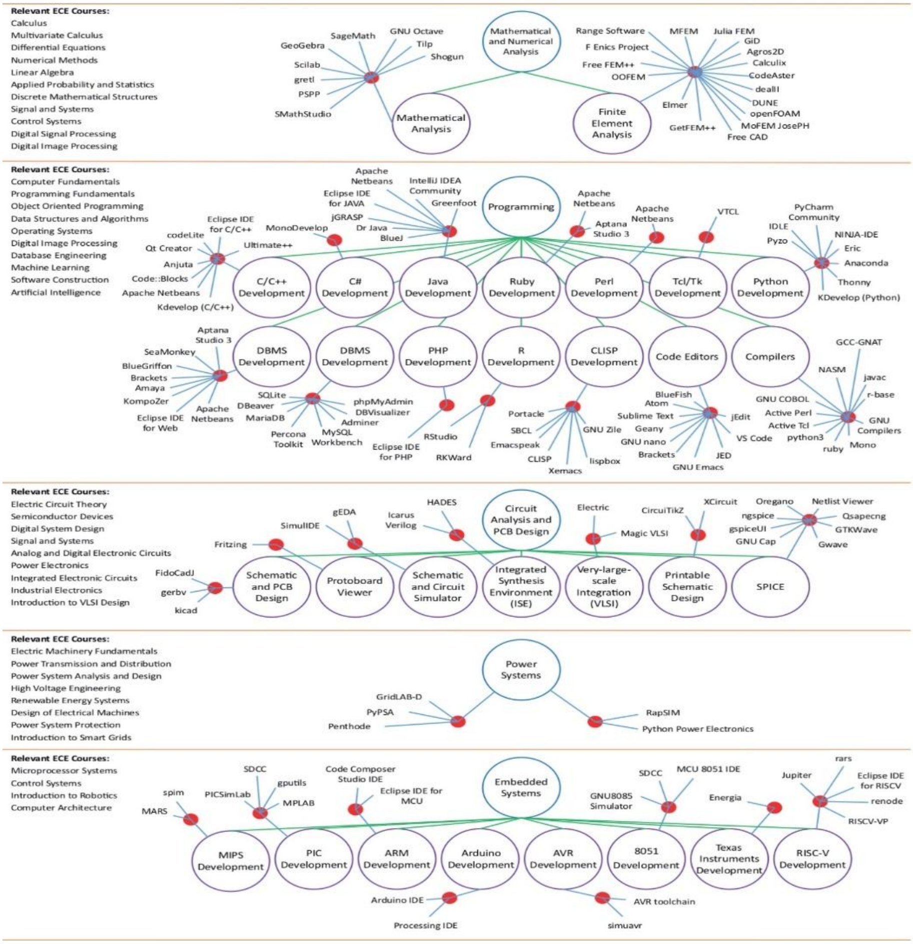


FIGURE 1. The tools incorporated in the SpecX package.

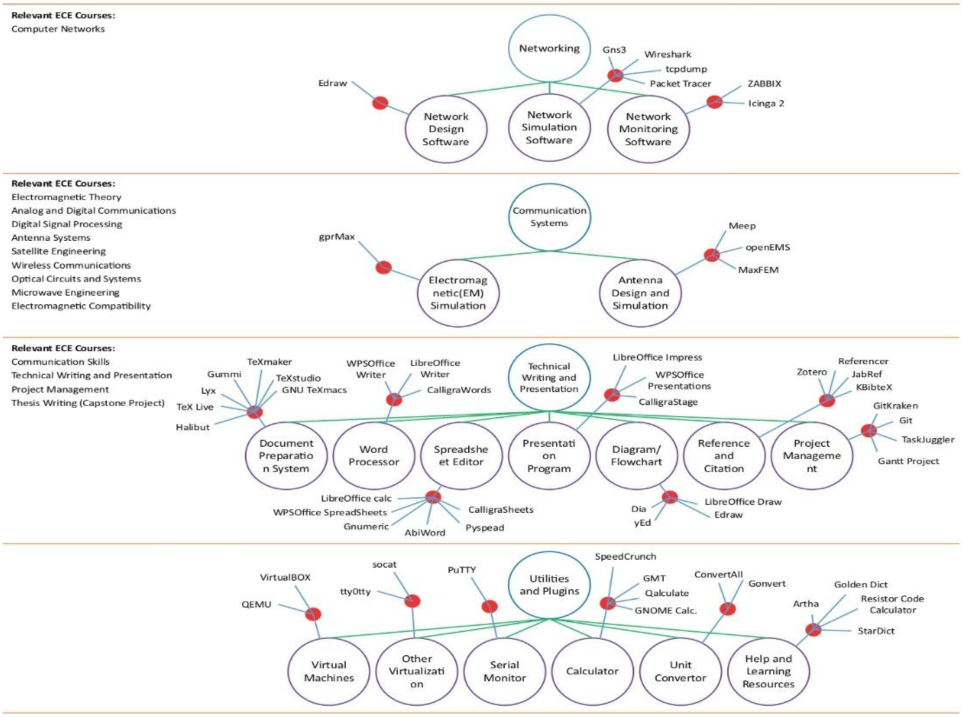
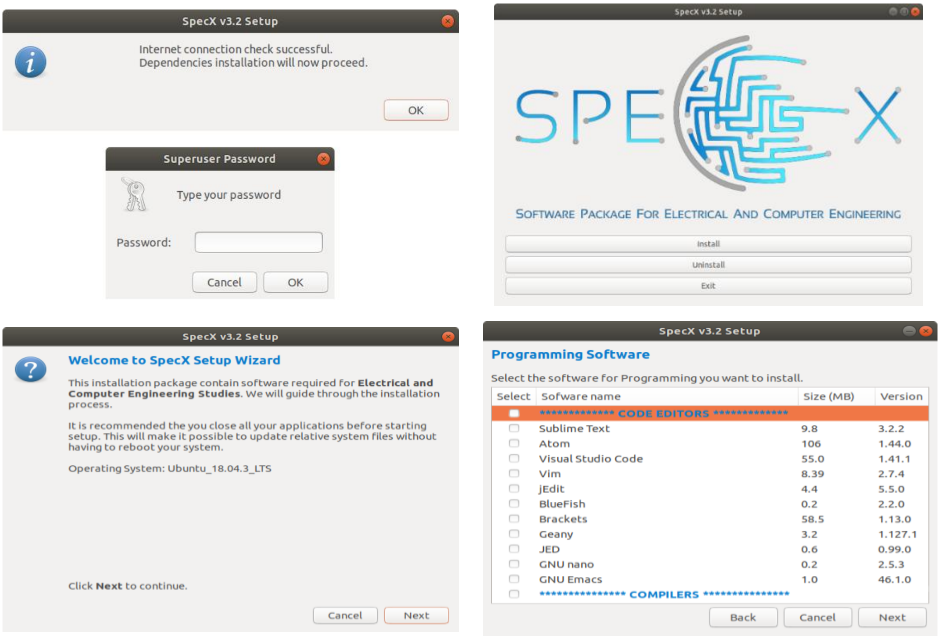


FIGURE 2. The 207 tools packaged in SpecX.


SpecX v3.2 Setup

Internet connection check successful.
Dependencies installation will now proceed.

OK

SpecX v3.2 Setup

SPECX

SOFTWARE PACKAGE FOR ELECTRICAL AND COMPUTER ENGINEERING

Install
Uninstall
Exit

Superuser Password

Type your password

Password:

Cancel OK

SpecX v3.2 Setup

Welcome to SpecX Setup Wizard

This installation package contain software required for **Electrical and Computer Engineering Studies**. We will guide through the installation process.

It is recommended the you close all your applications before starting setup. This will make it possible to update relative system files without having to reboot your system.

Operating System: Ubuntu_18.04.3_LTS

Click **Next** to continue.

Cancel Next

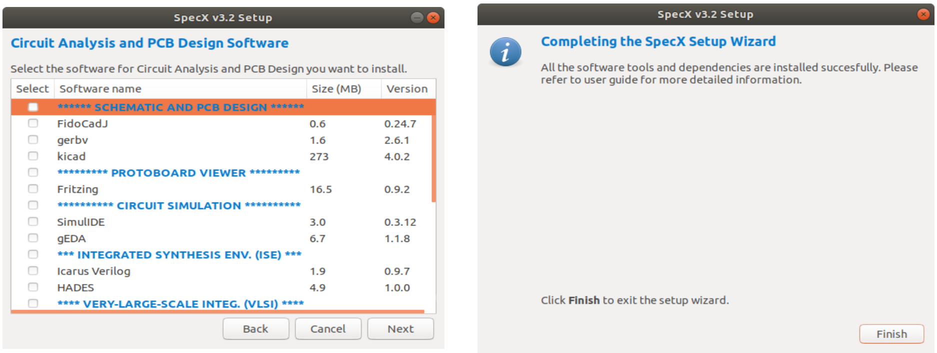
SpecX v3.2 Setup

Programming Software

Select the software for Programming you want to install.

Select	Sofware name	Size (MB)	Version
□	************* CODE EDITORS *************		
□	Sublime Text	9.8	3.2.2
□	Atom	106	1.44.0
□	Visual Studio Code	55.0	1.41.1
□	Vim	8.39	2.7.4
□	jEdit	4.4	5.5.0
□	BlueFish	0.2	2.2.0
□	Brackets	58.5	1.13.0
□	Geany	3.2	1.127.1
□	JED	0.6	0.99.0
□	GNU nano	0.2	2.5.3
□	GNU Emacs	1.0	46.1.0
□	*************** COMPILERS ***************		

Back Cancel Next



Circuit Analysis and PCB Design Software

Select the software for Circuit Analysis and PCB Design you want to install.

Select	Software name	Size (MB)	Version
□	****** SCHEMATIC AND PCB DESIGN ******		
□	FidoCadJ	0.6	0.24.7
□	gerbv	1.6	2.6.1
□	kicad	273	4.0.2
□	********* PROTOBOARD VIEWER *********		
□	Fritzing	16.5	0.9.2
□	********** CIRCUIT SIMULATION **********		
□	SimulIDE	3.0	0.3.12
□	gEDA	6.7	1.1.8
□	*** INTEGRATED SYNTHESIS ENV. (ISE) ***		
□	Icarus Verilog	1.9	0.9.7
□	HADES	4.9	1.0.0
□	**** VERY-LARGE-SCALE INTEG. (VLSI) ****		

Completing the SpecX Setup Wizard

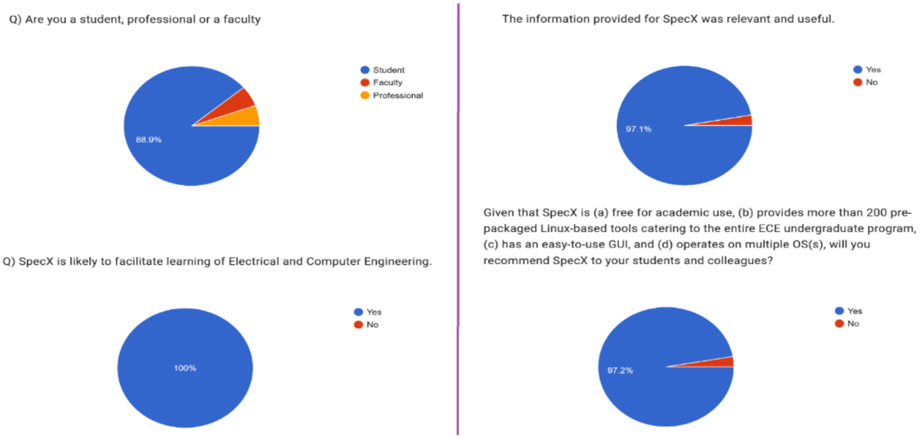
All the software tools and dependencies are installed succesfully. Please refer to user guide for more detailed information.

Click **Finish** to exit the setup wizard.

FIGURE 3. (a) checking internet connectivity and requesting sudo access. (b) install/uninstall screen. (c) installation guide screen. (d) programming software selection screen. (e) circuit analysis and pcb design software screen. (f) finalizing installation screen

Together, Figures 1 and 2 show 207 software categories under seven broad subjects, along with related ECE courses (as highlighted in Table I). The figure shows some dialog boxes which appear during the installation process. The Installation begins by (a) getting the superuser password and checking the internet connectivity. If the system is connected, installation of SpecX begins by first displaying the (b) install/uninstall selection screen, followed by a (c) welcome screen, and all the selection screens (d) and (e). Thereafter, the dependency and software installation screens are shown (for the sake of brevity use only some screens are shown). The process is completed by showing the (f) finish screen.

SpecX was evaluated in the laboratories of the author's university and proved very useful in developing ECE workstations, quickly and easily. Thereafter, a survey was conducted among students, faculty, and professionals to evaluate the usefulness of SpecX, as shown in Figure 4.



Q) Are you a student, professional or a faculty

The information provided for SpecX was relevant and useful.

Q) SpecX is likely to facilitate learning of Electrical and Computer Engineering.

Given that SpecX is (a) free for academic use, (b) provides more than 200 pre-packaged Linux-based tools catering to the entire ECE undergraduate program, (c) has an easy-to-use GUI, and (d) operates on multiple OS(s), will you recommend SpecX to your students and colleagues?

FIGURE 4. The results of a survey carried out to evaluate the usefulness of SpecX to ECE education

The survey also asked what they liked best about SpecX. The overall response has been very encouraging. Some responses are shown below:

- *"Free for academic use."*
- *"It includes multiple software packages which would really benefit upcoming students."*
- "*It will provide less time wastage for students seeking software that is supposed to install on their PCs. Furthermore, a great initiative for ECE students and faculty.*"
- "*The thing I like the most is that all EE courses are covered in this, with domains specified, covering every aspect.*"
- *"It's a complete all-in-one solution that would facilitate both the students and teachers."*
- *"This is a great opportunity for numerous students. Especially for those who have a lot of trouble with the pirated license keys."*
- *"All under one roof is the best quality of this package."*
- *"200+ free software(s)"*
- *"Great step to improve online study.*"
- *"I loved the approach towards automating the development of software workstations. It will surely make things easy and simple for faculty as well as students."*
- *"This initiative prohibits students from using pirate software and also easily accessible to students."*
- *"The whole package of knowledge will help students to improve their knowledge skills and also facilitate the teaching staff."*
- *"I think it is a great initiative for countries like Pakistan, where students don't have access to the required resources for their learning, experimentation, and executing research work. This will also save much more time because of the availability of a large set of tools within a single package.*"

IV. CONCLUSION

A number of Linux-based solutions are presented in the field of biology (Baari, Lxtoo, Open Discovery, PhyLIS, DNALinux, BioLinux) [1], and a similar effort is also needed in other fields. Understanding this need, and to provide immediate support to the students (in their lab and research work) and universities, this manuscript presented SpecX, a comprehensive software encompassing 207 ECE tools that are free for academic use, published after 2010, Linux-based, and work offline. SpecX is free to use by academia and licensed under AGPL-3.0. Lastly, the authors aim to continue updating SpecX with the help of valuable suggestions and feedback from faculty and students. Users are welcome to reach out to the authors via email.

CONFLICT OF INTEREST

The authors of the manuscript have no financial or non-financial conflict of interest in the subject matter or materials discussed in this manuscript.

DATA AVAILABILITY STATEMENT

Data supporting the findings of this study will be made available by the corresponding author upon request.

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