feature article

learn better by doing study

fourth-year results

Students learn by "doing" standards-based, hands-on activities.

by
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Students learn by "doing" standards-based, hands-on activities. Technology and engineering students learn by doing more than science and mathematics students. This finding may not surprise some educators. It is, however, important to realize that “millions of American youth spend precious little time tinkering, troubleshooting, or doing the kinds of hands-on problem-solving that are at the heart of technology and engineering” (Change the Equation, 2016, p. 1). Equally important is realizing that “people who are not literate in engineering and technology are too often doomed to be replaced by the technologies they cannot command.” (Change the Equation, 2016, p. 2). By *doing* in the classroom, technology and engineering students learn to “apply knowledge to new situations, to identify and solve unexpected problems without a playbook, [and] learn through ingenuity, failure, and perseverance” (Change the Equation, 2016, p. 2).

The purpose of the *Learn Better by Doing Study* was to determine the extent to which U.S. public elementary, middle, and high school students were *doing* hands-on activities in their science, technology, engineering, and mathematics (STEM) classrooms. ITEEA's Foundation for Technology and Engineering Education (FTEE), Dugger/Gerrish endowment provided support for this study.

This article will frequently refer to the Change the Equation study titled, *Vital Signs: Reports on the Condition of STEM Learning in the U.S.* The study reports results of the National Assessment of Educational Progress, Technology and Engineering Literacy (NAEP-TEL) Assessment administered to over 21,000 eighth grade students in 2014. The document discusses the importance of technology and engineering literacy and provides “concrete strategies for ensuring widespread literacy in technology and engineering" (Change the Equation, 2016, p. 9). It is important for education leaders to understand that the *Learn Better by Doing Study* addresses many of the concerns stated in the *Vital Signs* document.

This article presents data collected from the fourth and final Round of a longevity study on learning better by doing. The four rounds of the study were:

- Round 1, 2013-2014
- Round 2, 2014-2015
- Round 3, 2015-2016
- Round 4, 2016-2017

The authors present the implication of each finding, why they are important, and conclude with a call to action. The final report includes information gleaned from all four Rounds of the study.

The researchers solicited input from elementary, middle, and high school STEM teachers concerning standards-based activities that their students could have potentially done in their classrooms. Teachers were asked to respond "Yes" or "No" to 13 statements. The first two statements asked teachers if they felt that students learned by doing hands-on activities in class and whether they would have their students do more in class if they had the time and resources. The remaining 11 statements were grade-level specific (elementary, middle, and high school) and based on *Standards for Technological Literacy: Content for the Study of Technology (STL)* (ITEA/ITEEA, 2000/2002/2007), *Next Generation Science Standards (NGSS)* (Achieve, 2013a), and *Common Core State Standards for Mathematics (CCSSfM)* (CCSSO, 2010). Moye, Dugger, and Starkweather 2014a, and 2014b provide the methodology used in this study.

The researchers emailed surveys to approximately 30,000 elementary and secondary STEM teachers. Teacher participation was also encouraged by promotions in the *STEM Connections* newsletter, ITEEA conference promotions, ITEEA website, and personal researcher/teacher interaction.

Findings

The first general statement asked teachers if they felt that students benefit from doing activities to support learning. The second statement asked if they would assign their students more class projects if they had the time and resources. The total number of responding teachers was 1,840, including 327 elementary, 509 secondary science, 636 secondary technology and engineering, and 368 secondary mathematics teachers. Overwhelmingly, 99.4% of respondents felt that students benefit from *doing* activities, and 94.5% would have students do more in class if they had the time and resources. Table 1 identifies the

Table 1. Rounds 1, 2, 3, and 4 General Statements, Number of "Yes" Responses/Total Responses, and Percentages of "Yes" Responses.

	Elementary "Yes"				MS & HS Science "Yes"				MS & HS Technology and Engineering "Yes"				MS & HS Math "Yes"			
Statement	**2014**	**2015**	**2016**	**2017**	**2014**	**2015**	**2016**	**2017**	**2014**	**2015**	**2016**	**2017**	**2014**	**2015**	**2016**	**2017**
1. I believe that students benefit from doing activities to support learning.	433/437 99.1%	296/296 100%	222/225 98.7%	326/327 99.7%	399/404 98.8%	253/254 99.6%	270/270 100%	509/509 100%	540/544 99.3%	601/605 99.3%	297/298 99.7%	634/636 99.7%	282/285 98.9%	192/195 98.5%	257/257 100%	366/368 99.5%
2. Given the time and resources, I would assign my students more projects to do in class.	422/437 96.6%	288/296 97.3%	221/223 99.1%	320/327 97.9%	382/404 94.6%	242/254 95.3%	256/262 97.7%	481/509 94.5%	515/544 94.7%	568/606 93.7%	284/298 95.3%	549/636 86.3%	272/284 95.8%	177/195 90.8%	247/255 96.9%	348/368 94.6%

Table 2. Rounds 1, 2, 3, and 4 Elementary School Statements, Number of "Yes" Responses/Total Responses, and Percentage of "Yes" Responses.

Statement	Elementary			
My students have…	**2014**	**2015**	**2016**	**2017**
3. …developed an object, tool, process or system that included several criteria for success and constraints on materials, time, or cost.	198/365 54.2%	133/243 54.7%	93/155 60%	175/275 63.3%
4. …constructed an object using the design process.	196/365 53.7%	138/243 56.8%	104/155 67.1%	185/275 67.3%
5. …designed and built a product or system.	174/365 47.7%	119/243 49%	94/155 60.6%	160/275 58.2%
6. …controlled variables to conduct an investigation that produced data serving as evidence.	222/365 60.8%	149/243 61.3%	92/155 59.4%	173/275 62.9%
7. …performed an activity to solve a design problem.	198/365 54.2%	145/243 59.7%	91/155 58.7%	170/275 61.8%
8. …generated and compared multiple solutions to a design problem, based on the criteria and constraints of that problem.	153/365 41.9%	116/243 47.7%	69/155 44.5%	130/275 47.3%
9. …built a model and then improved the design to better meet requirements.	170/356 46.6%	118/243 48.6%	84/155 54.2%	156/275 56.7%
10. …tested and evaluated solutions for a design problem.	157/365 43%	114/243 46.9%	80/155 51.6%	146/275 53.1%
11. …built and used a model to communicate their solutions to a problem.	162/365 44.4%	116/243 47.7%	84/155 54.2%	133/275 48.4%
12. …built something designed to meet specific criteria and constraints.	217/365 59.5%	131/243 53.9%	106/155 68.4%	180/275 65.5%
13. …used a computer program to model and simulate a solution to a problem.	80/365 21.9%	60/243 24.7%	35/155 22.6%	64/275 23.3%
Total Yes Responses/Total Responses and Percentage of Doing in Courses	1927/4015 48%	1339/2673 50.1%	932/1705 54.7%	1672/3025 54.8%

two general statements, the number of teachers who responded "Yes," the total number of responses, and percentage of "Yes" responses for both statements in all four Rounds.

In addition to the two general statements, elementary, middle, and high school instruments contained 11 standards-based statements appropriate for each of the three grade levels. Teachers were also asked to respond "Yes" or "No" to those statements.

In Round 4, 275 elementary teachers responded to grade-level statements 3 through 13. The total percentage of students *doing* activities was 54.8%. Table 2 identifies elementary school statements 3 through 13, the number of teachers who responded "Yes," the total number of respondents, and the percentage of teachers indicating "Yes" to each statement. Elementary-level data for Rounds 1 through 4 are included. The last row of the table contains the number of "Yes" responses/total responses and percentages of *doing* at the elementary school level. The researchers derived the percentages by adding the number of "Yes" responses in the elementary column divided by the total number of responses in the same column.

A total of 514 middle school teachers responded to middle school statements 3 through 13. Of those respondents, 189 were science, 215 technology and engineering, and 110 were mathematics teachers. Table 3 identifies middle school statements, the number of teachers who responded "Yes," the total number of responding teachers, and the percentage of teachers indicating "Yes" to each statement. Middle school level data for Rounds 1, 2, 3, and 4 are included. The last row of Table 3 contains the number of "Yes" responses/total responses and percentages of *doing* in courses. The researchers derived these percentages using the same procedure as with the elementary data.

At the high school level, 853 teachers responded in this Round, of which 282 were science, 366 technology and engineering, and 205 mathematics. Table 4 identifies high school statements 3 through 13, the number of teachers who responded "Yes," the total number of responding teachers, and the percentage of teachers indicating "Yes" to each statement. High school level data for Rounds 1 through 4 are included. The last row of the table contains the number of "Yes" responses/total responses, and percentages of *doing* in courses. The researchers used the same procedure as with the elementary and middle school data to determine the percentage of *doing* at the high school level.
In order to determine the secondary percentage of *doing*, the researchers combined the middle and high school data for each secondary level content area. The total number of responding secondary teachers in Round 4 was 1367, of which 471 were science, 581 technology and engineering, and 315 mathematics.

Table 3. Rounds 1, 2, 3, and 4 Middle School Statements, Number of "Yes" Responses/Total Responses, and Percentage of "Yes" Responses.

Statement	MS Science				MS Tech. & Engineering				MS Math			
My students have…	**2014**	**2015**	**2016**	**2017**	**2014**	**2015**	**2016**	**2017**	**2014**	**2015**	**2016**	**2017**
3. …developed a solution to be tested and then modified it on the basis of the test results.	94/133 70.7%	61/83 73.5%	62/93 66.7%	134/189 70.9%	173/194 89.2%	192/218 88.1%	115/126 91.3%	195/215 90.7%	49/104 47.1%	26/65 40.0%	45/84 55.6%	53/110 48.2%
4. …created a tool or model to address an individual or societal need or want.	51/133 38.3%	37/83 44.6%	33/93 35.5%	103/189 54.5%	139/194 71.6%	161/218 73.9%	93/126 73.8%	158/215 73.5%	18/104 17.3%	11/65 16.9%	14/84 16.7%	28/110 25.5%
5. …tested and evaluated a design in relation to pre-established requirements.	92/133 69.2%	64/83 77.1%	62/93 66.7%	140/189 74.1%	177/194 91.2%	199/218 91.3%	113/126 89.7%	194/215 90.2%	34/104 37.7%	21/65 32.3%	34/84 40.5%	48/110 43.6%
6. …made a model to test for solutions to a problem.	85/133 63.9%	65/83 78.3%	52/93 55.9%	130/189 68.8%	169/194 87.1%	190/218 87.2%	105/126 83.3%	181/215 84.2%	52/104 50%	28/65 43.1%	47/84 56%	49/110 44.5%
7. …completed an activity that demonstrated how humans use natural resources that have positive and negative short and long-term consequences.	71/133 53.4%	47/83 56.6%	39/93 41.9%	87/189 46%	100/194 51.5%	119/218 54.6%	76/126 60.3%	122/215 56.7%	18/104 17.3%	5/65 7.7%	11/84 13.1%	18/110 16.4%
8. …created a model by applying criteria and constraints.	90/133 67.7%	64/83 77.1%	57/93 61.3%	147/189 77.8%	171/194 91.8%	202/218 92.7%	117/126 92.9%	202/215 94%	46/104 44.2%	28/65 43.1%	38/84 45.2%	54/110 49.1%
9. …designed and used instruments to gather data.	92/133 69.2%	57/83 68.7%	54/93 58.1%	127/189 67.2%	129/194 66.5%	144/218 66.1%	82/126 65.1%	148/215 68.8%	47/104 45.2%	36/65 55.4%	41/84 48.8%	47/110 42.7%
10. …analyzed and interpreted data to determine similarities and differences in findings.	120/133 90.2%	79/83 95.2%	81/93 87.1%	176/189 93.1%	146/194 75.3%	168/218 77.1%	100/126 79.4%	151/215 70.2%	84/104 80.8%	52/65 80%	66/84 78.6%	76/110 69.1%
11. …solved a design problem by developing an object, tool, process, or system.	69/133 51.9%	47/83 56.6%	44/93 47.3%	111/189 58.7%	165/194 85.1%	193/218 88.5%	112/126 88.9%	180/215 83.7%	26/104 25%	15/65 23.1%	21/84 25%	31/110 28.2%
12. …performed an experiment to solve a design problem.	88/133 66.2%	60/83 72.3%	43/93 46.2%	126/189 66.7%	137/194 70.6%	165/218 75.7%	104/126 82.5%	166/215 77.2%	21/104 20.2%	19/65 29.2%	21/84 25%	35/110 38.1%
13. …identified the characteristics of a design that performed the best during a test process.	79/133 59.4%	58/83 69.9%	49/93 52.7%	131/189 69.3%	158/194 81.4%	183/218 83.9%	102/126 81%	185/215 86%	18/104 17.3%	12/65 18.5%	22/84 26.2%	38/110 34.5%
Total Yes Responses/Total Responses, and Percentage of Doing in Courses	931/1463 63.6%	639/913 70%	576/1023 56.3%	1412/2079 68%	1671/2134 78.3%	1916/2398 79.9%	1119/1386 80.7%	1882/2365 79.6%	413/1144 36.1%	253/715 35.4%	360/924 39%	477/1210 39.4%

Based on Round 4 teacher responses, the percentage of secondary science doing was 59.1%, technology and engineering 77.2%, and mathematics 33.3%. Figure 1 contains elementary and secondary percentages for each round as well as four-year averages.

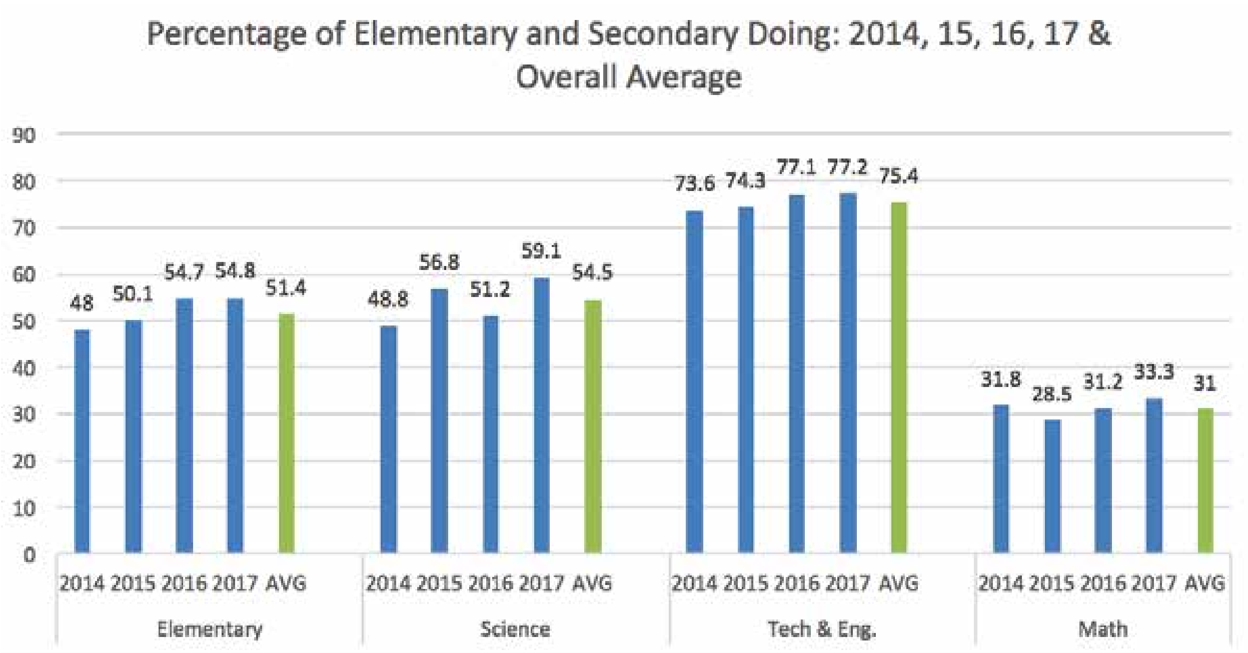

Figure 1. Elementary and secondary percentages of *doing* by content area for Rounds 1, 2, 3, 4, and four-round average.

Table 4. Rounds 1, 2, 3 and 4 High School Statements, Number of "Yes" Responses/Total Responses, and Percentage of "Yes" Responses.

Statement	**HS Science**				**HS Tech. & Engineering**				**HS Math**			
My students have…	**2014**	**2015**	**2016**	**2017**	**2014**	**2015**	**2016**	**2017**	**2014**	**2015**	**2016**	**2017**
3. …developed a solution to a complex real-world problem, based on scientific knowledge and student-generated sources of evidence.	111/220 50.5%	91/142 64.1%	77/130 59.2%	181/282 64.2%	245/308 79.5%	269/325 82.8%	100/129 77.5%	305/366 83.3%	68/151 45%	45/104 43.3%	61/127 48.0%	106/205 51.7%
4. …built a model of something to simulate the interactions between systems such as energy, matter, or information flow.	124/220 56.4%	95/142 66.9%	78/130 60%	215/282 76.2%	217/308 70.5%	226/325 69.5%	93/129 72.1%	281/366 76.8%	34/151 22.5%	23/104 22.1%	23/126 18.3%	45/205 22%
5. …created a presentation communicating the specifications and results of a design process used to meet a need.	90/220 40.9%	77/142 54.2%	76/130 58.5%	164/282 58.2%	242/308 78.6%	257/325 79.1%	110/129 85.3%	308/366 84.2%	52/151 34.4%	33/104 31.7%	39/126 31%	78/205 38%
6. …built a model using specified criteria and constraints.	154/220 70%	106/142 74.6%	91/130 70%	224/282 79.4%	285/308 92.5%	298/325 91.7%	118/129 91.5%	336/366 91.8%	70/151 46.4%	47/104 45.2%	56/126 44.4%	101/205 49.3%
7. …identified and applied criteria and constraints to develop a system or product.	94/220 42.7%	82/142 57.7%	68/130 52.3%	168/282 59.6%	275/308 89.3%	283/325 87.1%	122/129 94.6%	327/366 89.3%	54/151 35.8%	38/104 36.5%	47/126 37.3%	79/205 38.5%
8. …performed research to determine criteria and constraints driven by a societal problem.	96/220 43.6%	63/142 44.4%	68/130 52.3%	154/282 54.6%	184/308 59.7%	190/325 58.5%	79/129 61.2%	258/366 70.5%	40/151 26.5%	22/104 21.2%	22/126 17.5%	56/205 27.5%
9. …developed a solution to a major global challenge such as the need for improved health or supplies of clean water and food.	39/220 17.7%	31/142 21.8%	34/130 26.2%	91/282 32.3%	80/308 26%	63/325 19.4%	34/129 26.4%	123/366 33.6%	13/151 8.6%	3/104 2.9%	6/126 4.8%	18/205 8.9%
10. …applied the design process to evaluate an existing design or to collect data.	105/220 47.7%	86/142 60.6%	76/130 58.5%	167/282 59.2%	239/308 77.6%	256/325 78.8%	105/129 81.4%	311/366 85%	50/151 33.1%	30/104 28.8%	38/126 30.2%	81/205 39.5%
11. …built a prototype and checked it for quality and efficiency.	53/220 24.1%	49/142 34.5%	38/130 29.2%	106/282 37.6%	247/308 80.2%	269/325 82.8%	110/129 85.3%	307/366 83.9%	21/151 13.9%	17/104 16.3%	20/126 15.9%	25/205 12.2%
12. …used computer simulations to predict the effects of a design solution.	54/220 24.5%	41/142 28.9%	37/130 28.5%	79/282 28%	168/308 54.5%	188/325 57.8%	83/129 64.3%	230/366 62.8%	35/151 23.2%	15/104 14.4%	20/126 15.9%	35/205 17.1%
13. …evaluated a design solution by using conceptual, physical, or mathematical models to check for proper design.	44/220 20%	47/142 33.1%	38/130 29.2%	100/282 35.5%	216/308 70.1%	223/325 68.6%	91/129 70.5%	263/366 71.9%	42/151 27.8%	23/104 22.1%	28/126 22.2%	64/205 31.2%
Total Yes Responses/Total Responses, and Percentage of Doing in Courses	964/2420 39.8%	768/1562 49.2%	681/1430 47.6%	1649/3102 53.2%	2398/3388 70.8%	2522/3575 70.5%	1045/1419 73.6%	3049/4026 75.7%	479/1661 28.8%	296/1144 25.9%	360/1386 26%	688/2255 30.5%

Discussion

The purpose of the *Learn Better by Doing Study* was to determine the extent to which U.S. public elementary, middle, and high school students were doing hands-on activities in their STEM classrooms. The researchers asked elementary and secondary STEM teachers to respond "Yes" or "No" to 13 statements. The first two statements asked teachers if they felt that students learn by doing hands-on activities in class and if they would have their students do more in class if they had the time and resources. The remaining 11 statements were based on *Standards for Technological Literacy* (*STL*), *Next Generation Science Standards* (*NGSS*), and *Common Core State Standards for Mathematics* (*CCSSfM*).

In this (fourth) Round, 1835 of the 1840 (99.7%) responding teachers felt that students benefit from *doing* activities. The majority (1698 of 1840 - 92.3%) of those teachers indicated that they would have their students do more activities in class if they had the time and resources. Such a large percentage of teachers responding "Yes" to those two statements supports the idea that students learn better by doing. If students do learn better by doing, it stands to reason that they should be doing more standards-based, hands-on activities in their classrooms.

Again in Round 4, the secondary technology and engineering percentage of doing is higher than elementary, secondary science, and secondary mathematics percentages. This finding is consistent with the findings in each round. Although this report focuses on Round 4 information, it is interesting to see that the lowest secondary technology and engineering percentage, 73.6% recorded in 2016, is 14.5% higher than the next highest percentage of 59.1% found in secondary science in 2017. Based on this data, technology and engineering students are consistently doing more hands-on activities in their classrooms.

The statements teachers responded to can be grouped into different categories; for example, designing and modeling. When examining those two categories, specific trends and opportunities become evident.

Learning an engineering design process is beneficial for students' understanding of and ability to apply information. By using a design process, students "can integrate various skills and types of thinking—analytical and synthetic" (Katehi, Pearson, & Feder, 2009, p. 37).

In Round 4, teachers report that technology and engineering students used a design process 23.4% more frequently than science students and 44.1% more than mathematics students. Six statements reflecting design processes were used to make this determination. Those statements were middle school statements 9, 11, and 13 in Table 3 and high school statements 5, 10, and 13 contained in Table 4.

STL, *NGSS*, and *CCSSfM* all identify the importance of students learning by creating models. Referring to students who took the 2014 NAEP-TEL Assessment, the Change the Equation *Vital Signs* document identified that opportunities to build models "are few and far between for most students" (Change the Equation, 2016, p. 4).

In Round 4, teachers report that technology and engineering students model 18.6% more than science students and 52.1% more than mathematics students. Middle school statements 4, 6, and 8 in Table 3 and high school statements 4, 6, & 11 in Table 4 were used to make this determination.

Students in all three content areas are doing design and modeling activities in their classrooms. Since this is the case, the reader can recognize how STEM teachers could collaborate to create integrated lessons and assessments using design and modeling activities. Students receiving integrated studies and performing hands-on activities reinforcing those studies represent the epitome of STEM education.

Regardless of the low percentages, mathematics students are also using design and modeling as a *doing* activity. Mathematics teachers reported that their students completed design and modeling activities ranging from 12.2% to 55.4%. Clearly, mathematics can be and should be integrated into activities students do in science, technology, and engineering classrooms.

The National Mathematics Advisory Panel identified that a "sharp falloff in mathematics achievement in the U.S. begins as students reach late middle school" (NMAP, 2008, p. xiii). In addition to the "falloff in mathematics" students become less interested in education while in high school (NRC-IM, 2004). Moye, Dugger, and Starkweather (2016) reported that hands-on activities decreased between middle and high school. This decrease was again found in Round 4. The question still remains, "could there be a correlation between the amount of *doing* and student interest in school?" (Moye, Dugger, & Starkweather, 2016, p. 21).

NGSS identifies three categories of school resources. The first, material resources, "include time available for teaching, professional development, and collaboration among teachers [as well as] curricular materials, equipment, supplies, and expenditures." The second resource, human capital, includes "individual knowledge, skills, and expertise." The third identified resource is social capital, which stresses the need for "collaboration among teachers of different specializations and subject areas beyond the traditional forms of collaboration" (Achieve, 2013b, p. 33).

Teachers want their students to do more hands-on activities but have limited time and resources. Technology and engineering labs and classrooms contain STEM education material resources such as curricula, equipment, and supplies necessary to learn and practice STEM. Technology and engineering teachers are a source of human capital, possessing the knowledge, skills, and expertise that can help science and mathematics teachers learn and practice the art of integrative studies. Science and mathematics teachers could better utilize the social capital available by collaborating and performing collective decision making with technology and engineering teachers.

Conclusion – A Call to Action

The *Learn Better by Doing Study* has concluded, but this work is not complete. Technology and engineering professionals should now deliver the results to a broad audience that will better understand the importance of technology and engineering courses and programs. Often studies are conducted, only to be published with very little action taken based on the results. For example, the Change the Equation *Vital Signs* document states, "Decades of research suggests that people often learn best by testing solutions to real-world problems through hands-on trial and error. If the TEL survey results are any indication, [previous] research has had little impact on the nation's schools" (Change the Equation, 2016, p. 4). Technology and engineering professionals must take action on this study.

It is critical that people know how to apply knowledge in today's technologically driven society. Students must learn science, technology, engineering, and mathematics as well as be able to apply that information in daily situations. The U.S. education system has the resources needed to produce STEM-literate students. It is not evident, however, how all available resources are being used in the most productive manner. It is also not evident that technology and engineering programs are being utilized to strengthen STEM education in our schools.

With the assistance of the 5,910 teachers who participated in this four-year study, we now know where students are doing hands-on activities. Researchers are encouraged to glean information from the data provided in this study and publish key information supporting the need for and benefits of technology and engineering programs. Learning by doing is as vital to a student's education as cognitive learning is in today's technological world.

ITEEA has compiled all *Learn Better by Doing Study* articles and presentations at www.iteea.org/Activities/2142/Learning_Better_by_Doing_Project/50026.aspx#tabs.

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