Research on Informal STEM Learning (ISL)

An Annotated Bibliography of Selected Sources

About ISL: This whitepaper provides an annotated bibliography regarding research on STEM education in non-school settings. In the world of educational research, these programs are referred to as *informal* STEM education and/or *out-of-school* STEM education. **The National Science Foundation calls it *informal STEM learning*, so this paper will refer to that version of the subject title, and it will utilize the NSF's acronym, *ISL*.** Educational research in ISL is relatively scant in comparison to research on STEM education in schools, primarily because most research in STEM education focuses on the *formal* school curriculum, its teaching strategies, and its outcomes. Research on ISL is growing however, primarily because it can complement formal STEM education in the schools, and because it can happen throughout one's lifetime – from the earliest years of child development well into the senior years.

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Definitions

STEM – Acronym referring to the interrelated content of Science, Technology, Engineering, and Mathematics.

STEAM – Acronym referring to the interrelated content of Science, Technology, Engineering, the Arts, and Mathematics.

Informal STEM Learning (ISL) – A branch of education conducted outside of the traditional school curriculum focused on science, technology, engineering, and mathematics. ISL is "informal" learning because it does not occur in the "formal" school-based curriculum. Instead, ISL occurs during after-school hours, during visits to museums, science centers, or similar facilities, or during non-school weeks (school vacations) or months (summers). ISL can include all types of activities focused on one or more sciences, technologies, types of engineering, and/or fields of mathematics. It can include in-person activity, online activity, or a combination of both types of delivery.

Making (and/or Maker Spaces) – Relatively new terms associated with ISL student engagement using educational technologies focused on engineering design, testing, analysis, and decisionmaking. A *MakerSpace* is a facility in which "making" is used as an educational activity. Making can occur in the formal curriculum (in schools) or in informal settings.

Coding – The process of developing computer instructions to manipulate real-world devices or solve STEM problems with the aid of computers. Coding is a component of Making. Coding requires knowledge of the specific types of computer instructions (machine code) that control computing functions to solve real-world problems. (See *Translational Language*, below.)

Translational Language – Recent developments in coding include the development of "*translational language*" that can interpret commonly understood instructions into machine code. Translational language makes it possible code instructions into computers without learning the highly specific and complicated vocabulary and syntax of machine code.

Selected Books

National Research Council. (2015). *Identifying and Supporting Productive STEM Programs in Out-of-School Settings*. Washington, DC: The National Academies Press. https://doi.org/10.17226/21740, accessed 10/08/2016

- ✓ A relatively recent overview of STEM programs focused on Out-of-School settings, designed to help policy makers, funders and education leaders in both school and out-of-school settings make informed decisions about how to best leverage the educational and learning resources in their communities. The text identifies features of productive STEM programs in out-of-school settings. It also suggests further study, including research on design of out-of-school programs to better specify how culturally responsive and relevant out-of-school STEM learning experiences affect the short-term and long-term learning trajectories of young people, and research to better specify and understand the ways in which learning develops across formal and informal settings.

Bell, P., Lewenstein, B., & Shouse, A., & Feder, M. (eds.). (2009). *Learning Science in Informal Environments: People, Places, and Pursuits.* Washington, D.C.: The National Academies Press. https://www.nap.edu/catalog/12190/learning-science-in-informal-environments-people-places-and-pursuits, accessed 8/21/2015

- ✓ An early report by the Committee on Learning Science in Informal Environments, sponsored by the National Academy of Science in 2009. The report identifies six strands for ISL: 1) developing interest in science; 2) understanding science knowledge; 3) engaging in scientific reasoning; 4) reflecting on science; 5) engaging in scientific practice; and 6) identifying with the scientific enterprise. Suggestions for research are also provided.

Martiniz, S., and Stager, G. (2013). *Invent to learn: Making, tinkering, and engineering in the classroom*. Torrance, CA: Constructing Modern Knowledge Press

- ✓ Perhaps the most comprehensive book of the many new books on the Maker movement, Maker Spaces, Maker technologies, and informal STEM education.

Graves, C., and Graves, A. (2017). *The Big Book of MakerSpace Projects: Inspiring Makers to Experiment, Create, and Learn*. Columbus, OH: McGraw-Hill Education

- ✓ A broad and extensive description of MakerSpace projects for elementary and secondary-level students including instructions and tips for beginners and open-ended challenges for advanced makers. Descriptions feature non-technical, step-by-step instructions with photos and illustrations. Includes recyclables hacks, smartphone tweaks, paper circuits, e-textiles, musical instruments, coding and programming, and 3-D printing.

Selected Research Articles

Becker, K, and Kyungsuk, P. (2011). Effects of integrative approaches among science**,** technology**,** engineering**,** and mathematics **(**STEM**)** subjects on students**'** learning**:** A preliminary meta**-**analysis**.** Journal of STEM Education: Innovations & Research. Jul-Sep2011, Vol. 12 Issue 5/6, p23-37. http://web.b.ebscohost.com/ehost/detail/detail?vid=3&sid=ca9a88e7-fca7-4a73-81a6-7beb027d978f%40sessionmgr102&bdata=JnNpdGU9ZWhvc3QtbGl2ZQ%3d%3d#AN=72320466&db=a9h, accessed 04/24/2018

- ✓ Describes an early meta-analysis of research on varying approaches to STEM education. The analysis revealed that fully integrated approaches with all four subjects had the greatest effect size on elementary-level learning, and that the integration of all four subjects had greater effect sizes than integrations of fewer than all four at all levels. Overall, the study revealed that "integrative approaches among STEM subjects have positive effects on the students' learning." [Note: This article did not discuss ISL directly.]

Constan, Z. and Spicer, J. (2015). Maximizing future potential in physics and STEM: Evaluating a summer program through a partnership between science outreach and education research. *Journal of Higher Education Outreach and Engagement* 19 (2) 117 https://files.eric.ed.gov/fulltext/EJ1067019.pdf, accessed 08/07/2016

✓ Describes the validated research on a college summer program for high-school students in nuclear physics. Results include that participants (a) were more likely than nonparticipants to pursue an education and career in STEM, (b) were able to define and execute plans to solidify a strong foundation for pursuing a career in STEM, and (c) persisted in pursuing education in STEM after high school graduation.

Dabney, K., Tai, R., Almarode, J., Miller-Friedmann, J., Sonnert, G., Sadler, P., & Hazari, Z. (2011). Out-of-School Time Science Activities and Their Association with Career Interest in STEM. *International Journal of Science Education* (2) 1. https://www.tandfonline.com/doi/full/10.1080/21548455.2011.629455?scroll=top&needAccess=true, accessed 04/24/2018

✓ Describes results from a survey of college students ("Persistence Research in Science and Engineering" (n = 6882). Results indicate that students' participation in out-of-school activities, as well as their middle school interest in science and mathematics and their gender, plays a significant role in university career interest in STEM.

Densen, C., Hailey, C., Stallworth, C, & Householder, D. (2015). Benefits of Informal Learning Environments: A Focused Examination of STEM-based Program Environments. *Journal of STEM Education : Innovations and Research* (16) 1. *11-15*. https://search.proquest.com/docview/1689879030/fulltextPDF/9D8353882384975PQ/1?accountid=14076, accessed 4/24/2018

✓ Describes research on an out-of-school high-school STEM education program in California through which students out-perform other students in completion of advanced mathematics and physics courses, course grades, and college entrance exam scores. The research identifies eight aspects of ISL environments that contribute significantly to successful student learning: informal mentoring, making learning fun, time management, applications of math and science, feelings of accomplishment, confidence-building, and camaraderie.

Dorph, R., Schunn, C. D., & Crowley, K. (2017). Crumpled Molecules and Edible Plastics: Science Learning Activation in Out of School Time. *Afterschool Matters* 25, Spring 2017 http://activationlab.org/wp-content/uploads/2018/03/ASM_2017s_CrumpledMolecules.pdf , accessed 04/04/2018

✓ Defines and describes the Learning Activation Lab's overall approach to measuring "learning activation" in STEAM education using validated and reliable instruments with middle school and high school students.

Fields, D. A. (2009). What do students gain from a week at science camp? *International Journal of Science Education* 31(2), 151-171. http://digitalcommons.usu.edu/cgi/viewcontent.cgi?article=1185&context=itls_facpub, accessed 08/05/2016

- ✓ Describes the positive impacts of participation in a one-week summer science camp in astronomy for high school students. "Among the perceived benefits that students described were peer relationships, personal autonomy, positive relationships with staff, and deepened science knowledge. These perceived benefits appear to influence the kinds of identities students constructed for themselves in relation to science."

Halverson, E.R. & Sheridan, K. (2014). "The maker movement in education." *Harvard Educational Review, 84*(4), pp.495-504.

- ✓ Describes the theoretical roots of the Maker movement and draws connections to related research on formal and informal education. Provides guidance for continued research on outcomes in Maker Spaces.

Kier. M.W., et. al. (2014). The Development of the STEM Career Interest Survey (STEM-CIS). *Research in Science Education*. V44, N3, 461-481. http://eric.ed.gov/?id=EJ1039225 accessed 08/04/2016

- ✓ Describes the psychometric basis for a new validated survey to measure middle school students' developing interest in pursuing a career in STEM.

Martinez, S. & Stager, G. (2014). The maker movement: A learning revolution. Arlington, VA: International Society for Technology in Education (ISTE).

- ✓ Describes the wide variety of Maker Spaces and applications, the relation to different theories of learning, and the relationship to learning standards stressed in school curricula. Includes descriptions of specific technologies used in Making and their relationships to ISTE learning standards.

Mohr-Shcroeder, M., Jackson, C., Miller, M., Walcott, B., Little, D., Speler, L., Schooler, W., & Schroeder, D. (2014). Developing Middle School Students' Interests in STEM via Summer Learning Experiences: See Blue STEM Camp. School Science and Mathematics. (114) 6. October 2014. https://onlinelibrary.wiley.com/doi/abs/10.1111/ssm.12079, accessed 7/3/2017

- ✓ Describes an embedded mixed methods study design to investigate the extent middle level students' attitudes, perceptions, and interest in and toward STEM fields and careers changed after participating in an informal learning environment of a five-day day camp held on the campus of a major university in the mid-south. Results revealed an increase in student motivation and interest in STEM fields, including an increase from pre to post in interest in STEM careers. The data also revealed that a majority of the participating middle school students found the STEM content sessions "fun" and engaging, specifically citing the hands-on experiences they received.

National Science Foundation. (2015). *Women, Minorities, and Persons with Disabilities in Science and Engineering: 2015*. Arlington, VA: National Center for Science and Engineering Statistics.

- ✓ This is the most recent bi-annual report on "statistical information about the participation of these three groups in science and engineering education and employment. Its primary purpose is to serve as a statistical abstract with no endorsement of or recommendations about policies or programs. National Science Foundation reporting on this topic is mandated by the Science and Engineering Equal Opportunities Act (Public Law 96-516)."

Riskowski, J.L., Todd, C.D., Wee, B., Dark, M., & Harbor, J. (2009). "Exploring the effectiveness of an interdisciplinary water resources engineering module in an eighth grade science course" (PDF). *International Journal of Engineering Education, 25*(1), p.181.

- ✓ Describes statistically significant results of a controlled research study of active learning vs. passive learning of middle school students regarding engineering design for control of water resources. Students in the treatment group "displayed higher levels of thinking on open-ended questions and greater content knowledge. This research indicates the effectiveness of engineering in enhancing student learning and supports its inclusion in the middle school science curriculum."

Sahin, A., Mehmet C., & Adiguzel, T. (2014). STEM Related After-School Program Activities and Associated Outcomes on Student Learning. *Educational Sciences: Theory and Practice* (14) 1. *309-322*

- ✓ Describes outcomes of a study on after-school program activities at a charter school in the Southeast US. A qualitative case study design was employed to understand students' views and opinions regarding the activities and their learning trajectories. Study data were collected through formal and informal observations, one-on-one semi-

structured interviews, and field notes. The study's findings indicated that such activities should emphasize open-ended and collaborative scientific investigations in STEM.

Sha, L., Shun, C., & Bathgate, M. (2015). Measuring Choice to Participate in Optional Science Learning Experiences During Early Adolescence. *Journal of Research in Science Teaching*, *52, 5, 686–709* http://www.lrdc.pitt.edu/schunn/research/papers/Sha_et_al-2015-Journal_of_Research_in_Science_Teaching.pdf accessed 08/06/2016

- ✓ Describes the use of a validated and reliable Learning Activation Lab survey to measure differences among middle school students' choices to pursue science, technology, engineering, or mathematics in after-school programs.

Sheridan, K., Halverson, ER., Litts, B, Brahms, L., Jacobs-Priebe, L., & Owens, T. (2014). Learning in the Making: A Comparative Case Study of Three Makerspaces. Harvard Educational Review: December 2014, Vol. 84, No. 4, pp. 505-531.

- ✓ Describes features of three makerspaces and how participants learn and develop through complex design and making practices. Describes how the makerspaces help individuals identify problems, build models, learn and apply skills, revise ideas, and share new knowledge with others.

Terada, Y. (2016). Why Making Is Essential to Learning. *Edutopia*. San Rafael, CA: George Lucas Educational Foundation. https://www.edutopia.org/blog/making-is-essential-to-learning-youki-terada, accessed 5/25/2017

- ✓ Describes the importance of Making in informal STEM education. "At the heart of making is the idea that all students are creators, and hands-on learning plays a key role in maker education."

Vincent-Ruz, P., & Schunn, C. D. (2017). The increasingly important role of science competency beliefs for science learning in girls. Journal of Research in Science Teaching 54:790–822, https://onlinelibrary.wiley.com/doi/abs/10.1002/tea.21387, accessed 04/04/2018

- ✓ Describes validated results of Learning Activation Lab surveys of over 6000 middle school girls. "Multiple regression and mediation analyses show that as boys grow older, their willingness to engage in argumentation and to participate in science experiences suppresses the role of competency beliefs on their learning science content. By contrast, as girls grew older, they showed an increasing need to have high competency beliefs to achieve strong content learning gains. Our results demonstrate that despite girls'

willingness to participate in scientific argumentation and to take part in science experiences, they probably do not receive enough support in their environment to access the benefits of these experiences, and hence they have a stronger need to have high competency beliefs in order to achieve significant growth in science learning."

Wittemyer, R., McAllister, B., Faulkner, S., McClard, A., & Gill K. (2014). *MakeHers: Engaging Girls and Women in Technology Through Making, Creating, and Inventing* (PDF). Intel.

- ✓ Describes the Maker movement globally and the opportunities and challenges presented to girls and women in the movement, not only locally but throughout the world. Includes recommendations to engage girls and women in Making.

Wyss, V., Heulskamp, D., & Siebert, C. (2012). Increasing middle school student interest in STEM careers with videos of scientists. *International Journal of Environmental & Science Education*. 7, 4, 501-522. http://files.eric.ed.gov/fulltext/EJ997137.pdf accessed 08/04/2016

- ✓ Describes the positive impact of interviews with career STEM professionals on students interested in pursuing careers in STEM.

STEM Organizations and Reports

Alliance for Science & Technology Research in America (ASTRA)

- Founded in 2000, "ASTRA connects, convenes and communicates STEM policy and research findings across the U.S. and Global STEM ecosystem. Our goal is to improve the nation's R&D, Innovation and STEM Talent capacity by increasing funding, understanding — and importantly, the "messaging" about the importance of the global innovation ecosystem to policy makers."
- The **ASTRA State STEM & Innovation Report Cards** are the single best source for understanding each state's outstanding qualities and capacities. ASTRA's "Innovation X-Ray" also helps inform policy debates with specific and the most current data about federal funding, local economies, and workforce development.
- Key features of the 2017 State STEM & Innovation Reports include:
  - Ranking of States by 9 Key Innovation Metrics;
  - The Top 20 Industry Sectors for each state according to the concept of Location Quotient (LQ) — which provides strategic insight into a State's special strengths in terms of economic and workforce potential;
  - The Top 40 STEM Job Occupations projected for each state between 2016 and 2026;

  - The latest state AND national student attitude surveys on STEM careers (a noticable uptrend in STEM interest across the board concerning most enthnicities and gender in most states, and remarkable progress nationally); and
  - Updated data on student engineering degrees by ethnicity at the nation's top 10 Engineering Schools and survey data concerning high school students 'closing the gap between Classroom and Career'"
- **2017 ASTRA West Virginia Report**
  https://www.usinnovation.org/state/pdf_cvd/ASTRA-STEM-on-the-Hill-WestVirginia2017.pdf, accessed 4/25/2017
  - ✓ Features a wide variety of important metrics on the State's progress in meeting needs in terms of STEM jobs, education, minorities, innovation, and production.

American College Testing (ACT)

- "While ACT initially focused on assessing college readiness, ...ACT now offers more than 20 programs and services, providing support for all of life's transitions from elementary school through career."
- **ACT Annual STEM report** (2017)
  https://www.act.org/content/dam/act/unsecured/documents/STEM/2017/STEM-Education-in-the-US-2017.pdf, accessed 4/25/2017
  - ✓ Reports results on 2+ million students in the 2017 US high school graduating class—60 percent of all the nation's graduates—who took the ACT® test. The ACT is the only college readiness exam in the US with a full science test and also the only one that "reports a STEM score and a STEM College Readiness Benchmark score indicating students' readiness to succeed in college courses such as calculus, biology, chemistry and physics, which are typically required for a college STEM-related major."

Education Alliance

- A West Virginia nonprofit organization established 1983 to advocate for a quality public education for all West Virginia children
  - Serves over 21,000 students annually through AmeriCorps & WV eMentoring
  - Utilizes more than 1,300 volunteers to provide over 28,000 hours of service
  - Matches more than 1,300 students with a caring adult role model
  - Pairs 98 percent of West Virginia schools with at least one business partner
  - Provides sound research and data in public dialogues about education
- **Comprehensive Analysis of Summative Assessments Report (2017)**

http://educationalliance.org/default/assets/File/171637-EdAlliance-CASA%20report.pdf, accessed 04/02/2018
  - ✓ Analyzes commonly used national assessments of student learning and describes optimal criteria for WV assessment in the future

- **AmeriCorps STEM Toolkit (2017)**
  http://educationalliance.org/default/assets/File/AmeriCorps%20STEM%20Toolkit%20Final.pdf, accessed 04/02/2018
  - ✓ Provides ideas and lesson plans for students at varying grade levels to explore STEM topics and projects
- **A Brighter Future Begins Today – STEM Systems Building: A Strategic Plan for Support and Sustainability**
  http://educationalliance.org/default/assets/File/Report%20draft%20060916.pdf
  - ✓ Describes components of WV After-school STEM programs and support systems
- **West Virginia Council on STEM Report (2014)**
  http://educationalliance.org/default/assets/File/STEM%20report-Final%20for%20web.pdf, accessed 08/10/2015
  - ✓ Statewide report with recommendations for enhancing STEM education throughout WV. (STEM Hubs, STEM Clearinghouse, STEM Awareness)

Education Commission of the States (ECS)

The Education Commission of the States, originally established in 1964, partners with education policy leaders to address issues by sharing resources and expertise. ECS serves both the people who develop and implement education policy and the students who directly benefit from effective policy change. ECS produces *Vital Signs* annually, which provides analyses of four metrics important to the development of STEM in the US and in each state: STEM job growth, K-12 performance in STEM, preparation of STEM teachers, and STEM degrees for people of color.

- **US Vital Signs (2017)**
  http://vitalsigns.ecs.org/state/united-states/overview, accessed 09/30/2017
  - ✓ ECS produces *Vital Signs* annually, which provides analyses of four metrics important to the development of STEM in the US and in each state: STEM job growth, K-12 performance in STEM, preparation of STEM teachers, and STEM degrees for people of color.
- **WV Vital Signs (2017)**
  http://vitalsigns.ecs.org/state/west-virginia/overview ,accessed 09/30/2017
  - ✓ The West Virginia vital signs report featuring analyses of the same four metrics listed above.

Learning Activation Lab

The Learning Activation Lab is a collaborative among researchers from the Lawrence Hall of Science (UC Berkeley) and other prominent U.S. universities to develop easily-administered surveys to measure *Learning Activation (LA).* According to the researchers in the *Activation Lab*, interest and engagement in STEAM learning are components of what they define as *learning activation*, "a state composed of dispositions, practices, and knowledge that enable success in proximal science, technology, engineering, art, and mathematics learning experiences."[1] Learning Activation is a measure determined by using a combination of validated and reliable surveys of middle-level students' *fascination*, *values*, *competency beliefs*, and STEAM-based thinking skills (*scientific sense-making*, *mechanistic thinking*, *abstract thinking*, and/or *mathematical reasoning*) in project-based learning.

- **Research**
  http://activationlab.org/research/, accessed 5/25/2016
  - ✓ "The synthesis of past research, in conjunction with a collaborative theory-building process resulted a theoretical framework that positions researchers at the Learning Activation Lab to investigate this question in systematic ways across learning settings. This framework has multiple components: the activated learner, the trajectory of predicted outcomes, and the features of the learning experiences that support or maintain activation. Together these components posit a set of hypotheses that Learning Activation Lab researchers seek to investigate."
- **Instruments**
  http://activationlab.org/tools/ , accessed 04/04/2018
  - ✓ The Learning Activation Lab has developed and tested a variety of validated and reliable survey instruments, interview and observation protocols, and other instruments for use in STEAM research efforts. They include learning activation scales, engagement surveys and interview protocols, and associated surveys to examine demographics, collaboration, and perceived autonomy in STEAM activity.

NSF – Center for Advancement of Informal Science Education (CAISE)

The *Center for Advancement of Informal Science Education (CAISE)* is a NSF-funded resource center for the NSF's Advancing Informal STEM Learning (AISL) program. Among other things, it operates informalscience.org. The website is operated by the Center for Advancement of Informal Science Education (CAISE), an NSF-funded resource center for the Advancing Informal STEM Learning (AISL) program.

[1] http://www.activationlab.org/activation/, accessed 5/25/2016.

- InformalScience.org
  - ✓ A central portal with project, research, and evaluation resources designed to support and connect the informal STEM education community in museums, media, public programs, and a growing variety of learning environments.

STEM Education Coalition

The STEM Education Coalition is the largest and most unified voice advocating for changes in policies at the national, state, and local level to improve STEM education. Coalition members meet with members of congress, state officials, and local leaders to promote STEM education.

- **The Case for Investing in Out-of-School Learning as a Core Strategy in Improving Science, Technology, Engineering, and Mathematics (STEM) Education (2016)** http://www.stemedcoalition.org/2016/04/27/the-case-for-investing-in-out-of-school-learning-as-a-core-strategy-in-improving-stem-education, accessed 05/25/2016
  - ✓ "Citing the latest research on the value of informal STEM learning in cultivating student interest, expanding opportunities for higher learning, and building literacy and fluency in STEM knowledge and skills, the Coalition's new 10-page policy document includes a range of policy recommendations to address key challenges such as integrating informal and formal learning strategies, dedicated funding for informal STEM learning, professional development for educators, and expansion of the knowledge base."

WestEd (STEMworks)

WestEd is "a nonpartisan, nonprofit research, development, and service agency that partners with education and other communities throughout the United States and abroad to promote excellence, achieve equity, and improve learning for children, youth, and adults." WestEd features STEMworks, "a searchable online honor roll of high-quality STEM education programs. STEMworks helps companies, states, and individuals make smart investments in their communities by evaluating and cataloging programs that meet rigorous and results-driven design principles." STEMworks was originally a product of *Change the Equation*, a consortium on STEM-based US companies interested in promoting enhanced STEM education through corporate philanthropy. The companies now utilize WestEd to oversee and manage the evaluation process for prospective new programs.

- STEMworks Design Principles https://stemworks.wested.org/sites/default/files/STEMworks_Design_Principles.pdf, accessed 05/28/2016
- STEMworks Design Principles Rubric

https://stemworks.wested.org/sites/default/files/STEMworks_Design_Principles_Rubric.pdf, accessed 05/28/2016

West Virginia Development Office – Research Unit

- Tomorrow's Jobs (2012): The Best Career Opportunities in West Virginia Through 2020 http://workforcewv.org/images/files/job-seekers/tomorrows-jobs-2020.pdf accessed 08/02/2016

West Virginia University Center for Excellence in STEM Education

WVU's Center for Excellence in STEM Education (WVUCE-STEM) centers on research and best practices for STEM education, with particular focus in the State of West Virginia. The Center's objectives include designing and investigating STEM learning environments, providing rigorous preparation for STEM educators, increasing interest in STEM careers among K-20 students, enhancing the quality and supply of STEM teachers, meeting STEM job needs in the state, and increasing successful retention of students pursuing STEM majors at WVU.

- **STEM Education References**
  https://stemcenter.wvu.edu/faculty-resources/references, accessed 10/1/2017
  - ✓ A set of online resources and references for STEM education maintained and updated continually by WVUCE-STEM faculty.