STEM for All

By Paul Hutton and Todd VandenBurg

The Challenge

President Obama said in his 2011 State of the Union address that the United States is experiencing a second "Sputnik Moment," implying that we are challenged to keep up with our international competitors in training scientists and engineers. A recent review of academic performance rated the United States 17th in reading, 23rd in science, and 30th in math. Such poor performance may lead to further decline in our economic standing in the world.

As a result, the National Governors Association has made the following recommendations regarding Science, Technology, Engineering and Math, known widely as STEM:

- Align K-12 STEM expectations with readiness for all post-secondary pathways.
- Align STEM expectations to create a coherent K-12 system.
- Support promising new models of recruiting and preparing STEM teachers.
- Create STEM Centers to support improved teaching and learning across each state.

President Obama also said we need to "out-innovate" our competitors, and that "In America, innovation doesn't just change our lives. It is how we make our living." One of those innovations is the emergence of STEM as a driver of education reform. STEM has become a favorite term of educators, yet there is little consensus as to what that means or how it should be implemented. The recommendations above include the creation of STEM Centers, but there are no guidelines to design them. In this article, the authors will share their insights into the proper role of and implementation for STEM within the K-12 sector.

STEM School Models

STEM takes many forms within the K-12 sector, adapted to the needs of each district, community and student body. A few of the more typical STEM configurations are described below.

Public Magnet School – Many districts have created STEM schools that function as magnets for an entire district or portion of a district. These magnets frequently have admissions criteria and limited space and are, therefore, not available to all students.

Charter STEM School – Several charter schools have adopted STEM themed curriculum in whole or in part. Charter schools are still public schools and do not charge admission. Unfortunately, due to disparities in charter school building funding, charters rarely have facilities that allow for high-level science and technology instruction.

Private STEM Schools – Many independent schools have high-level science programs. A few even have STEM centers. Depending on available funding, STEM instruction may be basic or advanced, but it is not unknown for these institutions to include electron microscopes and genetic engineering labs at the K-12 level.

Vocational STEM – In some districts, STEM has been used to reinvigorate and modernize vocational-technical education. This is an appropriate recognition that technology has fundamentally changed basic professions such as auto mechanics and construction. These fields can be made more attractive to students by incorporating STEM principles and modern equipment.

STEM for All – We use this term to denote a public STEM school that is neither magnet nor charter, but is a fundamental part of a single feeder system. With this approach, every student has access to, and will participate in, some STEM education. And for those students who wish to focus on STEM, there are none of the typical barriers, such as a lottery or admissions tests.

Program and Curriculum Development

A STEM program should start by working with the local community, businesses, and post-secondary destinations to identify the desired outcomes. Examples of outcomes might be:

- Students create Career Plans specific to STEM fields;
- Success during the first year of college or post-secondary training with no remediation;
- Successful graduation from college or post-secondary training.

Typical secondary schools are organized around departments such as Math, Science, English, and History, with individual departments further subdivided, as in the case of Science having Biology, Chemistry, and Physics. STEM programs may be organized around specific themes rather than departments, with these themes driving curriculum and building layout.

Many of these themes are inherently inter-disciplinary and relate to specific career paths. Once the themes have been established, a next step would be to outline potential careers within each of the themes. Career paths may be as quasi-vocational as electrician or they may be as esoteric as astronomer. There may be as many as 40-50 career pathways that will be partly influenced by the local community. Having defined Themes and Career Paths, it is possible to develop a matrix outlining which courses should be taken to prepare a student for each, and in which year that course would ideally be taken. This matrix might be labeled Career Pathway Elective Options.

Lab Function and Layout

Labs are the heart of any STEM center. They should be spaces that encourage collaboration, experimentation, exploration and even wonder. Whereas traditional secondary school science labs have been dedicated to the specific disciplines of biology, chemistry, and physics, STEM labs may exhibit both higher levels of specialization and more variety. Examples of specialization would be genetic engineering and organic chemistry, while examples of greater variety would be robotics and avionics.

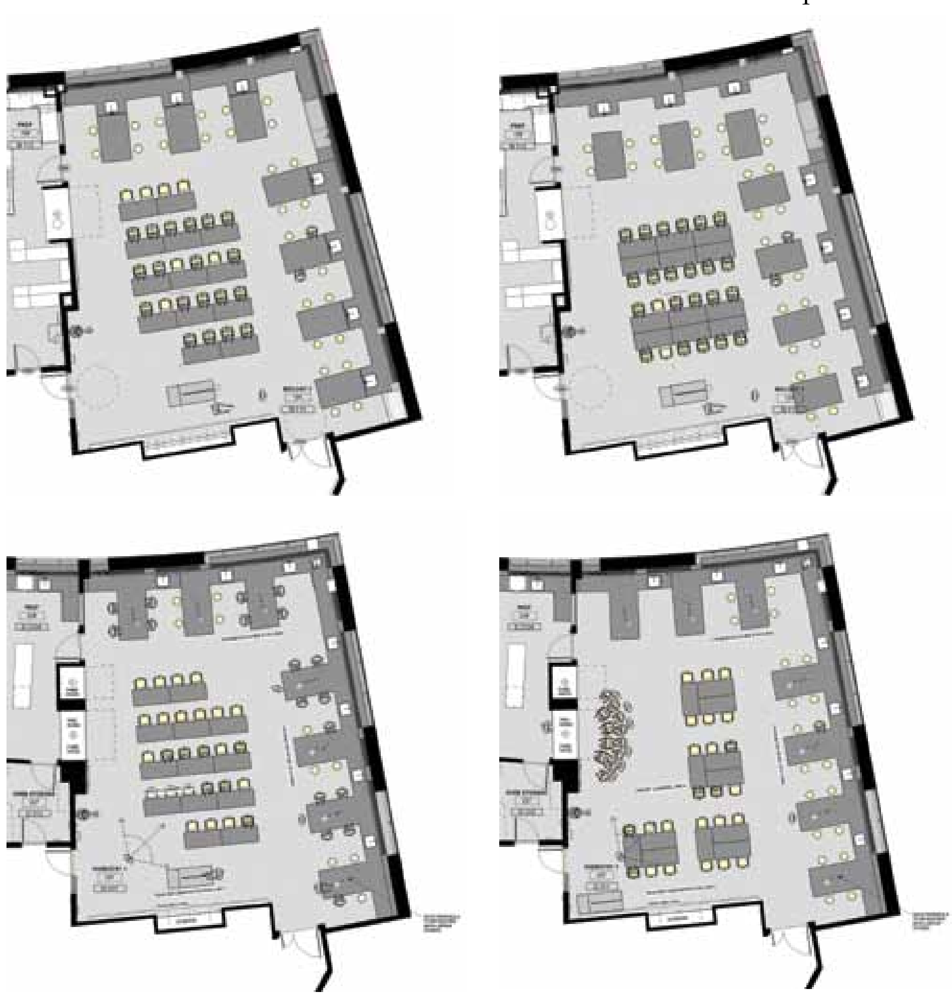
One frequently overlooked aspect of lab design is simply providing adequate space. We strongly believe in the standards promoted by the National Science Teachers Association (NSTA). It is important that the proper sizing of lab spaces be included in the programming phase, and protected throughout design and document development. These standards suggest a minimum of 60 square feet per student in secondary school and 45 square feet per student in primary school.

Project based learning has significant impact on the design of lab spaces. Incorporation of extra storage for projects underway is critical. Because one constant in education is change, we strive to make labs as flexible as possible. One obvious manifestation of this approach is that we rarely utilize fixed islands with utilities. We also rely heavily on movable and re-configurable furnishings. We understand that labs for different disciplines have very different needs. We therefore design each lab individually, and avoid repeating one lab design/layout for multiple spaces.

Specifics of the plans include exterior work stations which frame group learning areas that can be configured in a variety of ways, all viewable by the teacher; teaching space around the fume hood; and additional storage behind the teaching wall.

Developing Partnerships

Many successful STEM programs have nurtured relationships with local



Plans of the same lab, indicating the flexibility of the space.
Top Images: Biology – Bottom Images: Chemistry

institutions and businesses. On the institutional side, community colleges, four year colleges and other technical career centers benefit from formalized relationships with K-12 STEM centers. These institutions currently spend billions of dollars annually on remedial education for recent high school graduates and appreciate that excellent STEM education can reduce this burden. Partnership results include offering college level courses to STEM students, guaranteeing admissions to STEM graduates under certain pre-defined conditions and identifying scholarship opportunities for STEM students.

On the business side, companies welcome the opportunity to provide input on the attributes they seek in the future work force. Benefits of corporate partnerships include internships, externships, provision of teaching resources and donation of equipment.

STEM for Young Students

As the STEM movement has expanded to include more districts and more schools, it has also expanded into a broader range of grade levels. We believe this is critical to the success of the STEM movement. Children have an innate sense of wonder about nature, and encouraging this sense rather than ignoring it can only have positive benefits as those students grow older. Science/Math instruction at the elementary level is all too often weak and uneven, especially in comparison with other industrial countries. It may be difficult to introduce STEM into elementary schools, but an alternative is to take elementary school students, at least on an occasional basis, to a STEM center for enrichment activities.

K-8 schools, in place of separate Elementary and Middle Schools, are a growing trend in the United States. This is partly due to operational efficiency and cost-effectiveness, but the K-8 configuration offers greater opportunity for STEM enrichment at all grade levels. Because grades 7 and 8 frequently have basic science labs, these spaces can be utilized on an occasional basis by younger students. In larger K-8 schools, we have designed specialized STEM labs for use only by grades K-5. This approach offers the opportunity to custom design the STEM lab to accommodate the size of K-5 students and equip it with safe and appropriate equipment.

Sustainable STEM Buildings

Two of the most prominent movements in K-12 education today are STEM and Green Schools. Fortunately these two movements have much in common and can be readily combined in a single school building. In fact, many aspects of sustainable or "Green" design lend themselves to incorporation in a STEM facility. Students today are generally quite knowledgeable about environmental issues and many of them care deeply about the state of the world. Students will not respect the building they are placed in if that building does not in turn respect the larger environment through low energy use and responsible stewardship of resources. And their attitude toward the building will reflect upon their attitude toward the program itself.

We typically establish clear energy and sustainable goals at the beginning of every educational project and STEM centers are no exception. What may be different at STEM facilities is that these goals may be even more ambitious, and energy use and sustainability are put on display even more prominently. In establishing energy goals for a K-12 STEM center it is important to realize that STEM buildings tend to use more energy than typical schools due to the lab spaces. The typical K-12 school building in the U.S. today uses approximately 79 kBTU/square foot/year. New schools are averaging significantly less than that, thanks to more demanding energy codes and voluntary programs such as LEED and CHPS. Whatever the energy target established, STEM Centers may use up to 10 kBTU/sf/year more than their non-STEM counterparts.

Buildings as Sustainable Teaching Tools

As important as it is for STEM buildings to be examples of energy efficiency and sustainability, it is even more important for STEM buildings to become teaching tools about the importance of sustainability. It should be possible for STEM students to readily grasp the primary energy conserving features of their building and to monitor actual real-time performance of those features and the building as a whole. When this capability is provided, teachers will find ways to utilize that information in their lessons.

Energy dashboards have been used for a few years to display energy and other resource usage to building occupants. Although these can be effective, we find that most often they are quickly forgotten. We have therefore instituted new measures to arm students with the kind of information they need to change human behavior. In a recent STEM school, we equipped all eight of the basic labs with E-mon energy monitors. These are mounted on the wall adjacent to the main entrance door, and can be seen by every student on the way in and out of the Lab. These E-mons are set up in a most unusual way; rather than only monitoring and recording power used by outlets in the room, they also monitor all the electric lighting in the lab as well. In this way, each of the E-mons records all electrical energy usage in the room. Students from any Lab can compare their electrical energy use to all the other labs and they can chart their own energy use over time.

If there are photovoltaic panels at a STEM center, they should be connected to a Building Automation System that allows students to access output data in real time and to study the interface between that output and overall building performance. Another method of using the building as a sustainable teaching tool is to make many of the environmental control systems available for student viewing. At a recent STEM center, we have detailed a pathway through the accessible basement, from which most of the critical HVAC equipment may be observed.

Buildings Teaching Science and Math

Science buildings have long incorporated science themes, but these banal graphics are quickly ignored by the occupants of those buildings. A typical example is depiction of the periodic table in floor or ceiling tiles of a Chemistry Lab. We believe that STEM buildings can incorporate scientific and mathematical themes on a deeper level. Occasionally such design elements may even lie undiscovered by building occupants for a long time.

Students often complain that science instruction isn't relevant to their lives or that they don't know why they should care about it. In reality, science and math surround us and are present in everything we do. We believe that a modern STEM building should make "visible" those scientific components and organizing principles. A recent example of this approach is the inclusion of geodetic lines into a terrazzo floor. The lines represent half seconds of both latitude and longitude and are accurate to 4". By measuring the distance between lines, students can use trigonometry to calculate the dimensions of the earth.

We find that teachers will incorporate these into their lesson plans, and we frequently encounter students busily measuring or recording building features as part of an assignment.

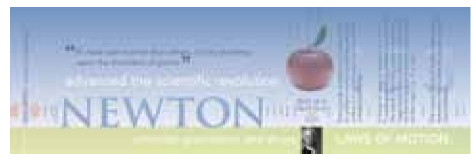
The History and Personalities of Science

Math instruction in the U.S. has generally failed to hold student interest for a variety of reasons. Some theorists have questioned student motivation, and others have looked into cultural biases. There may be validity to these and other issues, but we believe that one area of pedagogical failure has been the insistence on making these subjects "objective" and in the process depersonalizing, even dehumanizing, them. No wonder students lose interest.

The scientific method seeks objectivity, but it is still conducted and advanced by very real people. We

believe that STEM should be taught in conjunction with an awareness of those personalities who have contributed most to its advancement through history. To do otherwise would be akin to teaching English as grammar without literature.

For this reason, we seek ways to introduce humanity back into STEM. An example is the use of visually rich murals about a wide variety of scientists, mathematicians, technologists and other creative individuals. One of the important lessons from such a depiction is the incredible inter-connectedness among disciplines and across time. STEM is all about making connections, and seeing them where others had not.



Information Technology

As Clayton Christensen has observed in his influential book "Disrupting Education," Information Technology (IT) has already changed education, and it will change education even more in the future. Smartboards and similar technologies are already ubiquitous throughout STEM centers and schools in general. Video-teleconference facilities are another staple, allowing content to be generated off site and made available locally. A valid question is whether IT in STEM buildings or STEM portions of buildings should be any different than other classrooms. We believe there are subtle differences in the integration of IT in STEM centers.

The world of IT is ever changing. This is exemplified by innovations in tablet PC's that have challenged the role of lap top and desk top PC's. Touch screens and touch pads are another innovation that is challenging our perception of how we interface with computers. Voice recognition technology is also improving rapidly. There are many new technologies and new markets developing at an alarming rate. In IT, "Change" is the one common characteristic. STEM classrooms must be planned to adapt to technological change.

STEM instructors are innovators and quite often first adaptors of new technology - they must have classrooms that can be scaled to their needs. In IT, these needs translate to access to data over a network. Dependent on the amount of data they are pushing and/or their need for mobility and convenience, they may require access to a network by wifi and/or hard wire connection. To accommodate this need for flexibility, both methods of connecting should be provided in all teaching spaces.

One perspective on the need for wireless and hard wire connection is that as the ability for wireless transmitters to transfer larger amounts of data increases, so does the size of the files that are being developed for programs that run on computers that operate at faster speeds. In many cases, such as intense graphics, wireless speeds are not fast enough for the larger data thru-put. In addition to wifi, STEM classrooms should have an array of floor data connections to allow for possible connection of equipment so that advanced programs that push large amounts of data can be used.

From the FF& E perspective, new computer hardware must be purchased on a regular basis. Likewise, budgeting for equipment replacement must be done on a regular basis. From the facilities design and construction perspective, the infrastructure must be robust, redundant and scalable. It is recommended to have redundant wireless coverage to prevent dead spots. It is also recommended that rooms be equipped with multiple floor and wall network connection points.

STEM classrooms should have the network infrastructure to allow for flexibility in furniture configuration for wired network connections. They should also be equipped with wireless connection points to allow for portability and convenience. Where possible, these connections and wireless transmitters should be part of a clearly organized labeled network of cables in accessible ceilings, chase spaces, oversized conduits and cable trays. IT systems must be planned with change in mind in order to be adaptable to new technologies.

Conclusion

As we implement more and more STEM centers in our K-12 schools, we will no doubt see ever greater variety of approach and design. This is appropriate as the STEM concept adapts to many different communities, circumstances and budgets. But, we sincerely hope all of them will retain certain basic features, including:

- Focus on desired outcomes;
- Emphasis on sustainability;
- Integration, rather than isolation, of disciplines;
- Inclusion of human aspects of STEM;
- Thoughtful planning of progressive IT. ■

Paul Hutton, AIA, CAE, LEED AP is the founding principal of Hutton Architecture Studio, in Denver, Colorado. From its origin more than 20 years ago the firm has been dedicated to creating high performance, daylighted, environments for learning. Paul has conducted research, lectured, and written extensively about daylighting schools for nearly 30 years. He developed and still teaches the daylighting and sustainability course at the University of Colorado at Denver College of Architecture. The firm's Aspen Middle School was Colorado's first completed LEED NC Gold school building. Since early 2009, Hutton Architecture Studio has partnered with the Governors Energy Office to administer the state's High Performance Building Program. Paul lives on a sustainable ranch south of Denver, where he is actively pursuing the goal of living at zero net energy.

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