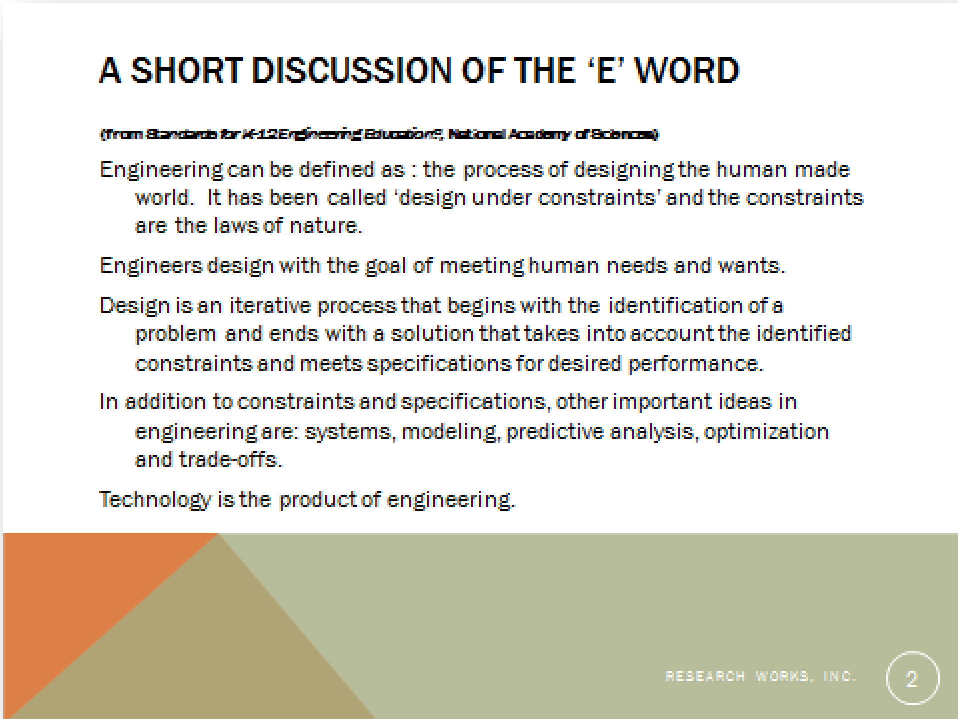
This presentation takes you through some background material on the present 'state of play' in one strand of educational research concerned with the development of appropriate instructional designs for the efficient and effective delivery of STEM related content in P-12 education.

This is not a presentation of a fait accompli, however, and should not be treated as such. This is one strand of thinking, not the only one, and one where the components have been tested but not the combination of those components into an 'approach'. But we believe it does offer an interesting set of components with their own long history of research indicators, that, taken together, might give us a starting point for a real run at developing a comprehensive approach to STEM learning and teaching that has a high potential of success.

While this presentation is delivered at the request of the Mathematics Center for Learning and Teaching at Hunter College, City University of New York, it contains the work of Research Works, Inc. who is solely responsible for the content of this presentation.

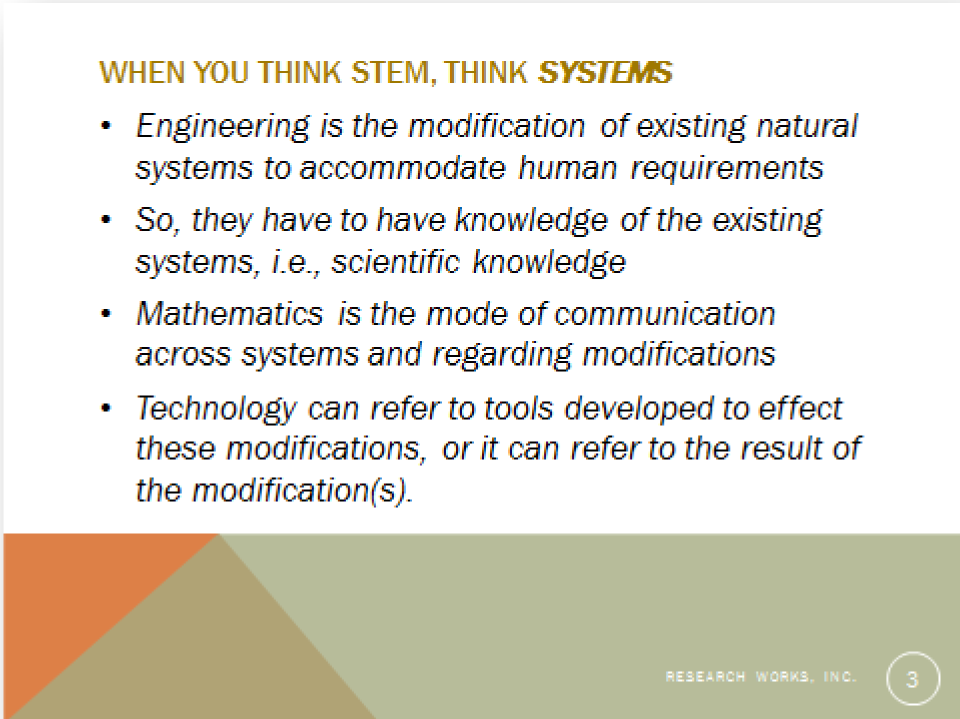


"The word engineer is derived from the Medieval Latin verb *ingeniare,* meaning to design or devise (Flexner, 1987). The word *ingeniare* is, in turn, derived from the Latin word for engine, *ingenium*, meaning a clever invention. Thus, a short definition of engineering might be "the process of designing the human-made world using clever inventions."

Remember that engineering is 'design under constraint', meaning that engineers have to consider the nature of the systems into which their design decisions will be implemented and with which those newly modified systems will interact.

It is important to understand the relationships among the components of STEM. The two that P-12 education knows the most about are science and mathematics. The relationship between these two disciplines has a long history, probably because both are trying to discover general patterns and relationships, and in that sense are part of the same endeavor. Mathematics is the chief language of science, as such the symbolic language of mathematics has turned out to be extremely valuable. Both disciplines have an underlying assumption of understandable order; an interplay of imagination and rigorous logic; ideals of honesty and openness; the use of technology to open up new fields of investigation; and etc.

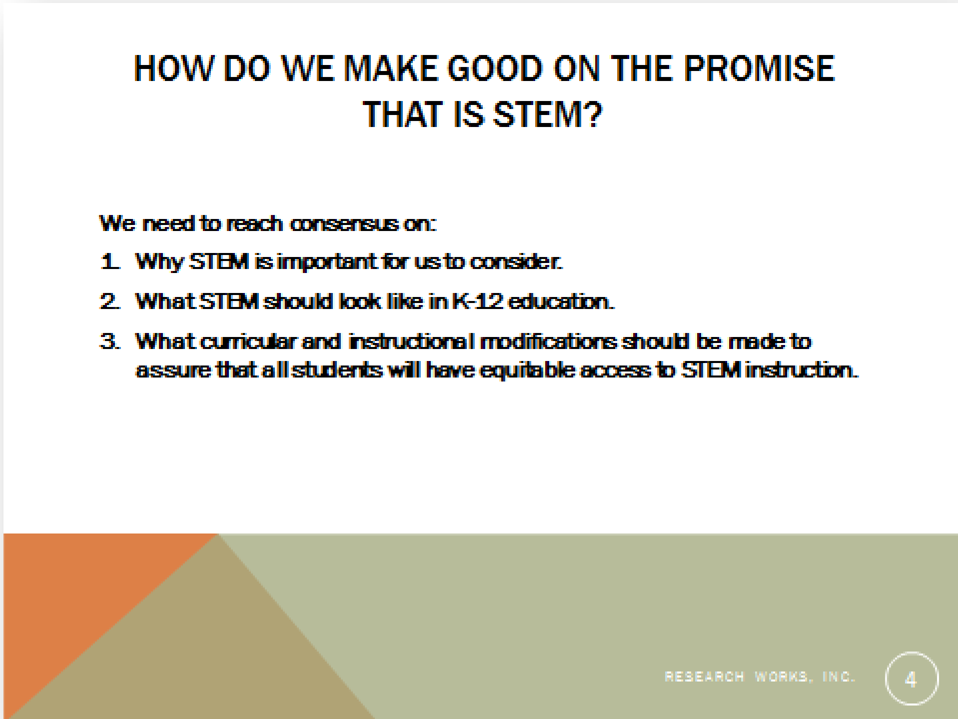
Mathematics also has a connection with technology (obviously in the development of computer programming language, for example, but also in the scaling and design of other technology types from automobiles to space craft). There is also a more general connection to engineering, as in describing complex systems whose behavior can then be simulated with design features and operating conditions varied as a means of finding optimum designs.



"In contrast (to engineering), science is derived from the Latin noun *scientia*, meaning knowledge, and is commonly described as the study of the natural world. Whereas scientists ask questions about the world around us-what is out there, how do things work, and what rules can be deduced to explain the patterns we see-engineers modify the world to satisfy people's needs and wants."

"Of course, in the real world, engineering and science cannot be neatly separated. Scientific knowledge informs engineering design, and many scientific advances would not be possible without technological tools developed by engineers."

"Mathematics is the science of patterns and relationships … A central line of investigation in theoretical mathematics is identifying in each field of study a small set of basic ideas and rules from which other interesting ideas and rules in that field can be logically deduced … Mathematics is also an applied science. Many mathematicians focus their attention on solving problems that originate in the world of experience. They too search for patterns and relationships, and in the process they use techniques that are similar to those used in doing purely theoretical mathematics. The difference is largely one of intent."



Some assumptions have to be taken as a given:

1. **K-12 Education has a clear set of purposes** – that being that the appropriate education of each generation of a democratic society is not up for debate. The definition of 'appropriate education' and whether the definition of appropriate differs according to the class, gender, ethnicity or other population characteristics of the members of that generation are, however, widely debated.
2. Historically, in the United States **this definition has been articulated and controlled by each individual State.**
3. Within the discipline field of education certain components of practice are agreed to as critical.

- Curriculum: defined as the skills and content that is taught.
- Instruction: defined as the means by which that content is communicated.
- Assessment: defined as the procedure to establish that the communication has been successful.

Why should we care about STEM? There are three main areas of argument in favor of a FOCUS on this area of curriculum and instruction.

One: It's role in Systemic Education Reform in the US. This is important to STEM mainly because we are in the middle of systemic reform, like it or not. So, as "The theory of systemic reform states ... A coherent complement of programs and policies can produce powerful reform by creating reinforcing and synergistic effects. " (Supovitz and Taylor, 2005), STEM as one set of these programs and policies makes sense.

Two and Three: Are closely related, so it is a little complex. Two is about a general ability of all students to innovate and three is about ensuring that our next generation has the ability to innovate in STEM related fields.

Two: One of the outcomes of schooling should be the ability to innovate. However:

"A strong consensus is emerging among scientific, business, and education leaders that America's ability to innovate and compete in the global marketplace is directly tied to the ability of our public schools to adequately prepare all of our children in STEM."
(National Governors' Association, *Building a Science, Technology, Engineering and Mathematics Agenda,* 2007)

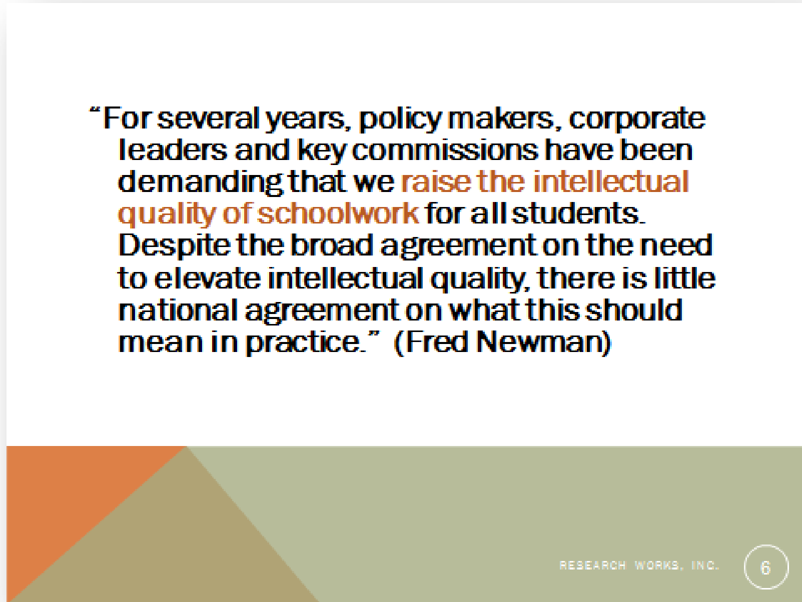
The United States developed a 'culture of innovation' for a number of reasons. Space won't allow a really in-depth discussion, but there are at least two contributing factors widely believed to have nurtured this national characteristic. One is a matter of geography. Colonial and then independent status could not move North America closer to Europe, necessitating the new country's settlers developing survival technologies that could be produced here. Later, the sheer size and distances of the large geographic expansion of the country during the nineteenth and early twentieth centuries led to generations of new settlers who often had to devise their own applied technologies to survive in settlement areas. Americans respect the person who figures out a way to 'get the job done' with as little drama as possible! The second contributor was the establishment of the 1-12 education system, finalized just after World War I. This is important for numerous reasons, but the Readers' Digest version is that we were the first nation to establish free secondary education for all (qualified) students, just after World War I – something not largely implemented in European nations, for example, until after World War II. That free secondary education included college preparation academic studies and, in some States, skilled occupation training that included some academic components. This meant that the American workforce was comprised largely of functionally educated innovators so that regardless of the level at which barriers or challenges were presented, those working at that level could (and most often did) fashion a temporary or permanent solution.

Changes to the American system of schooling (certainly following WW II and the wave of change that Sputnik in 1959 and the American response beginning with the Coleman Report a few years later), especially its move towards more academically focused or college preparatory only high school curriculums (concentrating on theoretical mathematics, pure science, English curricula based on literary criticism rather than linguistics, and so on), along with the closing down of applied professional schools at the college/university level, have been discussed as some of the contributing factors to a breakdown in the 'culture of innovation'. One thing society seems to be asking us to do is to reverse this trend.

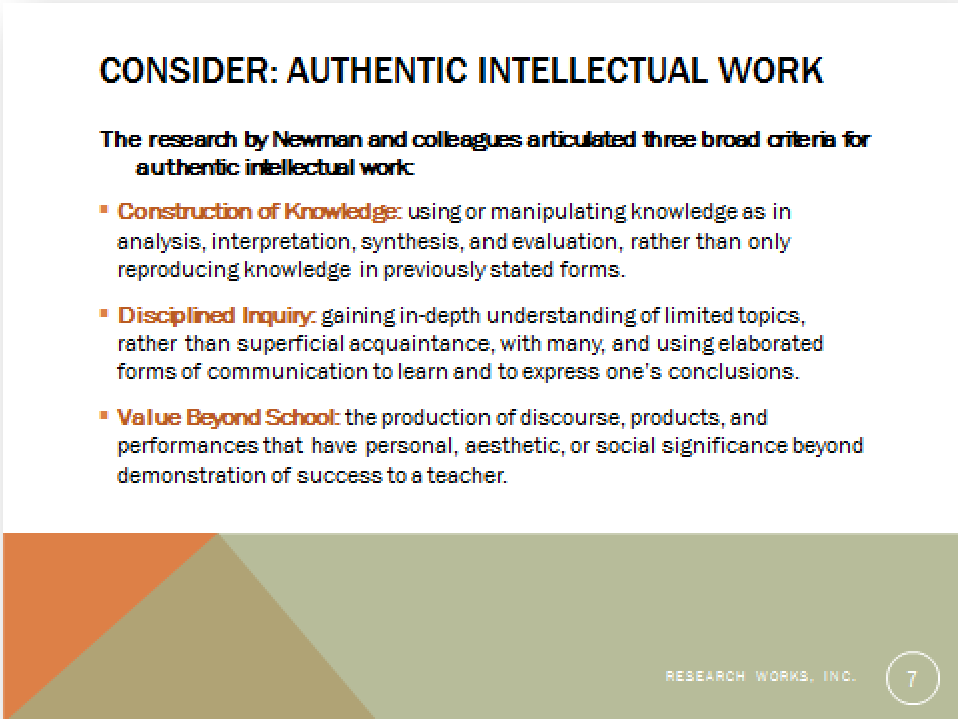
Three: Ensure a pipeline of engineer innovators in order to support ongoing development of our culture. Writers on this are more or less unanimous on the point that in order to continue to grow and prosper societies have to constantly change, adapt and develop. One mechanism that is necessary for that change, adaption and development is constant innovation in all areas and as support of development in all the society. I know I'm stealing this from somewhere, just can't find the cite at the moment, will find and provide.

So, if the public (which includes all typical education stakeholders as well as the wider stakeholder group of all taxpayers – many of whom are employers – who pay for public education, and non-taxpaying citizens) wants change, what does that look like and how does STEM fit into the present change environment, or does it, and if not, should it?

Another important aspect of Systemic Reform is its emphasis on challenging standards for students – 'raising the bar' on the level of depth and complexity of content across all disciplines in general education in the US; the alignment of the policy components of education governance (curriculum, assessments, accountability systems, teacher certification requirements, pre-service and in-service training), supported by an assumption of the support of school flexibility to develop the strategies to best suit the needs of their students.



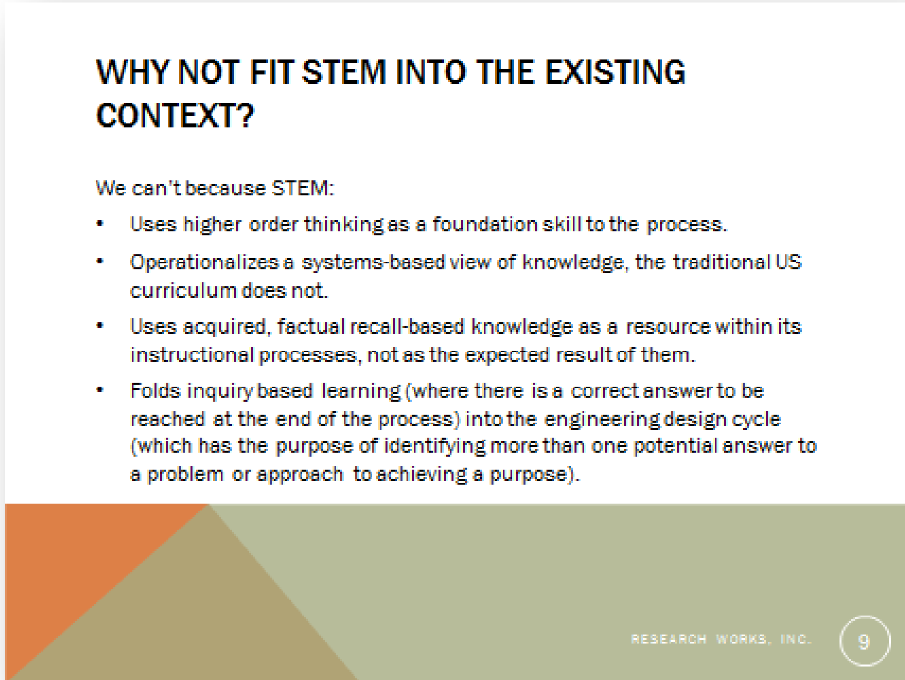
Research at the Center on Organization and Restructuring of Schools (CORS) is a collaboration across three universities in the US (University of Chicago; University of Wisconsin-Madison, and University of Illinois at Urban-Champagne). Starting with an analysis of the cognitive activity of adults who work successfully with knowledge in a variety of occupations and settings (e.g. journalists, jurists, designers, teachers, auto mechanics, photo copy technicians, customer service representatives, physicians and child care providers), they identified 'authentic' intellectual work, defined as such because it requires high-level cognitive performance, that is, rigorous, in-depth understanding instead of only superficial acquaintance with memorized bits of knowledge. Thereby the CORS group has proposed a conception of high quality intellectual work that can be used to evaluate the level of intellectual quality of diverse curricula, assessments, and student work products without taking a stand on specific content that ought to be learned.



Why promote authentic intellectual work as a basis for identifying the content of some of the curriculum and the related instructional processes that would be necessary to include it?

1. Success in work, civic participation, and managing personal affairs demands it.
    - All demand critical thinking, problem solving, communication and team work skills in order to construct knowledge through disciplined inquiry to solve problems in the real world.
2. Participation in authentic intellectual activity appears to motivate students to invest in the hard work that learning requires, including learning the basics.
3. The criteria for authentic intellectual work provides a link to results based planning in schools and school districts.
4. This approach fits with the Core Content State Standards now being promulgated around the country and in New York State. It is tailored to the in-depth coverage of limited curriculum topics of these new standards.
5. In relation to instructional time concerns and the Common Core State Standards (CCSS) implementation, this approach will enhance the ability of the teacher, curriculum specialist, or instructional supervisor to combine content across the curriculum in ways that will maintain

content rigor while making time use in classrooms more efficient and thus lead to more effective instruction.

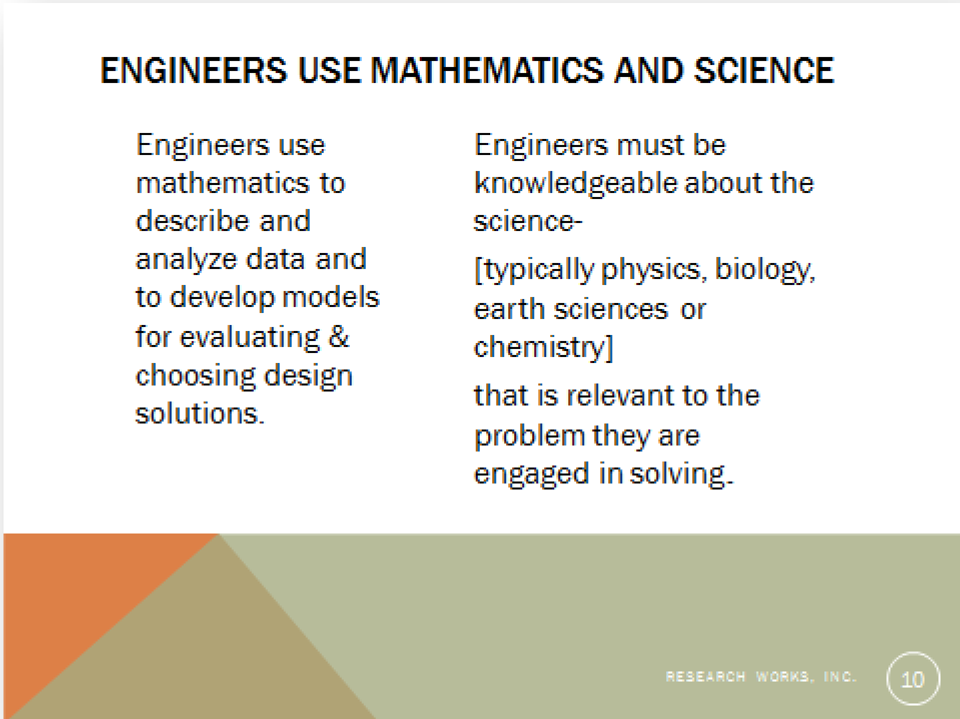


The most recent work in STEM related learning and teaching, here in the US and elsewhere in the world, emphasizes that the subject areas of science and math are not *integrated* in STEM in the manner familiar to the typical American curriculum integration model. Instead, they are used as applied sources of knowledge and process, illustrated by the definition of engineering as the application of scientific knowledge within the confines of mathematical reasoning to change nature to suit the needs of human society.

From there, the facts that STEM learning and teaching uses higher order thinking and a systems-based view of knowledge are defining of the challenge facing us. As is the point that because STEM uses the factual recall based knowledge from within these disciplines as a resource, rather than as the object of instruction, it is critical to define STEM in terms of a complex applied knowledge undertaking.

The difference between inquiry based learning (where students work to arrive at THE correct answer) and learning based on the engineering design cycle (where students identify a number of possible solutions and choose the best among them based on mitigating factors) is pretty clear. The best engineering solution operates with a definition of quality as ‘best fit to need’, rather than a definition of quality as ‘most accurate depiction of existing fact’.

That students in one unit of study might at different points use either the inquiry based model or the engineering design cycle is inevitable, since the legitimacy of engineering practice is based on its anchor to scientific knowledge. Since an understanding that these two processes are not interchangeable is important for students to grasp, one learning trajectory here would be for students to learn to identify for themselves which questions are suited to one or the other process.



Writers on STEM instruction in P-12 schooling in the US are divided on the instructional area that should act as the 'content junction' in STEM. In other countries this is not an issue, with just about everyone else in the world choosing Engineering as the junction area. Because of that, I have chosen to adopt the international practice and assume that we want to see Engineering as the 'content junction' and work from there, for the purposes of this presentation. **I do not mean to present this as already agreed upon, but I had to choose somewhere to drop my curricular anchor, and so engineering is that somewhere. An area for discussion, and perhaps not an 'all or nothing' circumstance as we are talking about covering a very broad spectrum of student ages, developmental stages, and degrees of ability.**

So, if engineering is the content junction then understanding how mathematics and science content and curricular epistemology function in engineering practice is something we have to articulate. These descriptions of how engineers use these two core content areas for STEM are drawn from the literature reviewed for this presentation.

And, we need some agreed upon definitions. I propose these (taken from the Internet):

Project-Based Learning is an individual or group activity that goes on over a period of time, resulting in a product, presentation, or performance. It typically has a time line and milestones, and other aspects of formative evaluation as the project proceeds.

Inquiry-based learning is an instructional style based on the idea that learning may be facilitated by giving students the opportunity to explore an idea or question on their own. To arrive at an answer or to better understand the concept, students often collect and analyze data.

The engineering design process is the set of steps that a designer takes to go from first, identifying a problem or need to, at the end, creating and developing a solution that solves the problem or meets the need.

- The steps of the engineering design process are to:
  - **Define the Problem**
  - **Do Background Research**
  - **Specify Requirements**
  - **Create Alternative Solutions**
  - **Choose the Best Solution**
  - **Do Development Work**
  - **Build a Prototype**
  - **Test and Redesign**
- During the engineering design process, designers frequently jump back and forth between steps. Going back to earlier steps is common. This way of working is called **iteration**, and it is likely that your process will do the same!
- While engineers create new things, such as products, websites, environments, and experiences, scientists study how nature works.
  - If your project involves making observations and doing experiments, your project might better fit the Steps of the Scientific Method.
  - If you are not sure if your project is a scientific or engineering project, you should read Comparing the Engineering Design Process and the Scientific Method.

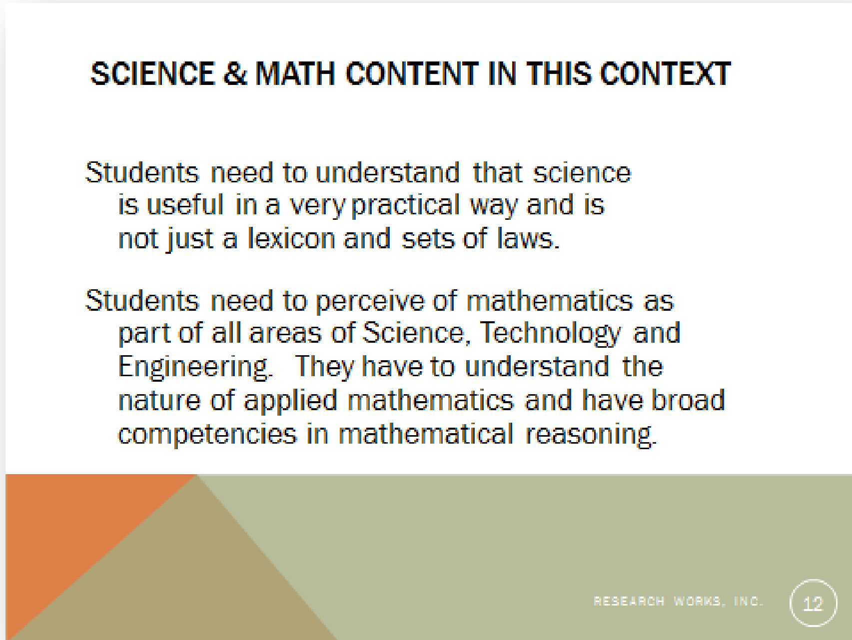
Comparing the Engineering Design Process and the Scientific Method.

Both processes can be broken down into a series of steps, as seen in the table below.

The Scientific Method	The Engineering Design Process
State your question	Define the problem
Do background research	Do background research
Formulate your hypothesis, identify variables	Specify requirements
Design experiment, establish procedure	Create alternative solutions, choose the best one and develop it
Test your hypothesis by doing an experiment	Build a prototype
Analyze your results and draw conclusions	Test and redesign as necessary
Communicate results	Communicate results
Steps of The Scientific Method	Steps of The Engineering Design Process

Keep in mind that although the steps above are listed in sequential order, you will likely return to previous steps multiple times throughout a project. It is often necessary to revisit stages or steps in order to improve that aspect of a project.

Downloaded June 6, 2012 from http://www.sciencebuddies.org/engineering-design-process/engineering-design-process-steps.shtml



Taken together, the two statements on this slide actually could be a pair of bell weather statements for anyone beginning to implement the new Common Core State Standards, and thus add to the instructional value of including content to support STEM learning and teaching.

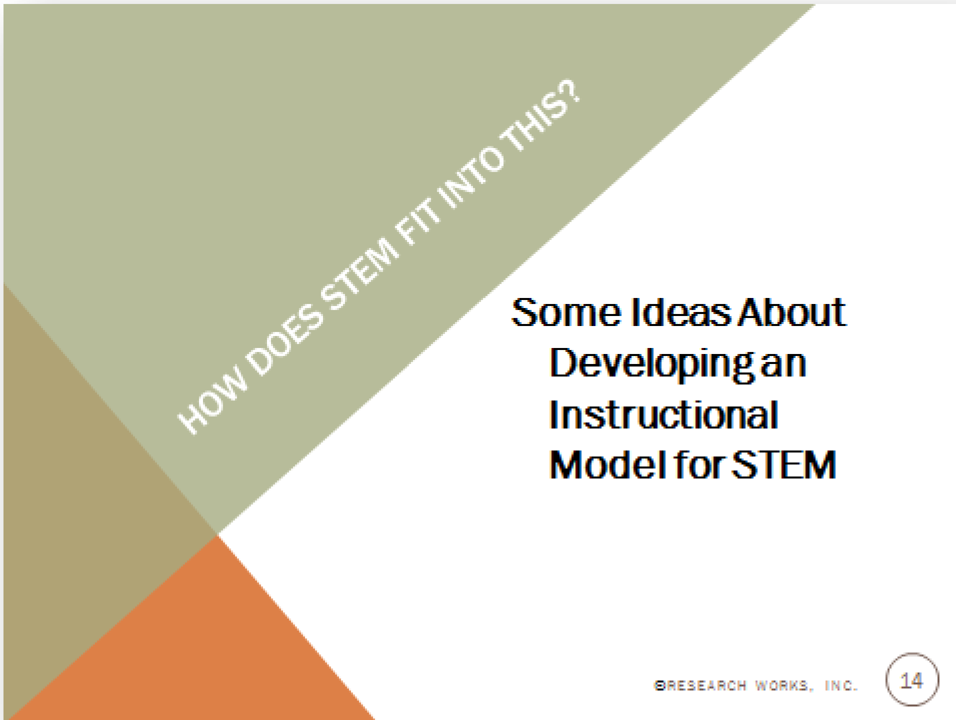
With the new common core standards and their less breadth – more depth promise, the first statement certainly is. Any school which continues to define 'knowledge' as the efficient retrieval of factual information will soon find themselves adrift in the world of the new standards. The question then becomes: "If learning science is not just learning a lexicon and sets of laws, then what is it?" And how do we obviate applied mathematics to our students?

Research reviewed for this presentation make the emphatic point that students have to learn how to construct knowledge based on their foundational understanding of **fact** and not opinion, sense of or collective wisdom of their peers.

So, **if** the point is to encourage the use of a definition of knowledge that includes some aspects we generally refer to as understanding.

- Curriculum experts agree that developing the ability to seek understanding as a learner means that you first must have access to a level of basic knowledge and skills that is both necessary and sufficient for that engagement.
- In addition, it seems obvious that science and mathematics provide the facts of STEM learning and teaching.
- Therefore, this means that it is important to establish each student's 'base domain' of knowledge and skills [because students combine their levels of basic knowledge and skills in these and other areas within the core curriculum in order to be able to function as learners and constructors of knowledge using a STEM curriculum].

It is this, the establishment of each student's base domain as the starting point of instruction, not the expected outcome of instruction that is important, revolutionary, and a real game changer in American education. You may have spent your career thinking this was always the case, but it has not heretofore been so.



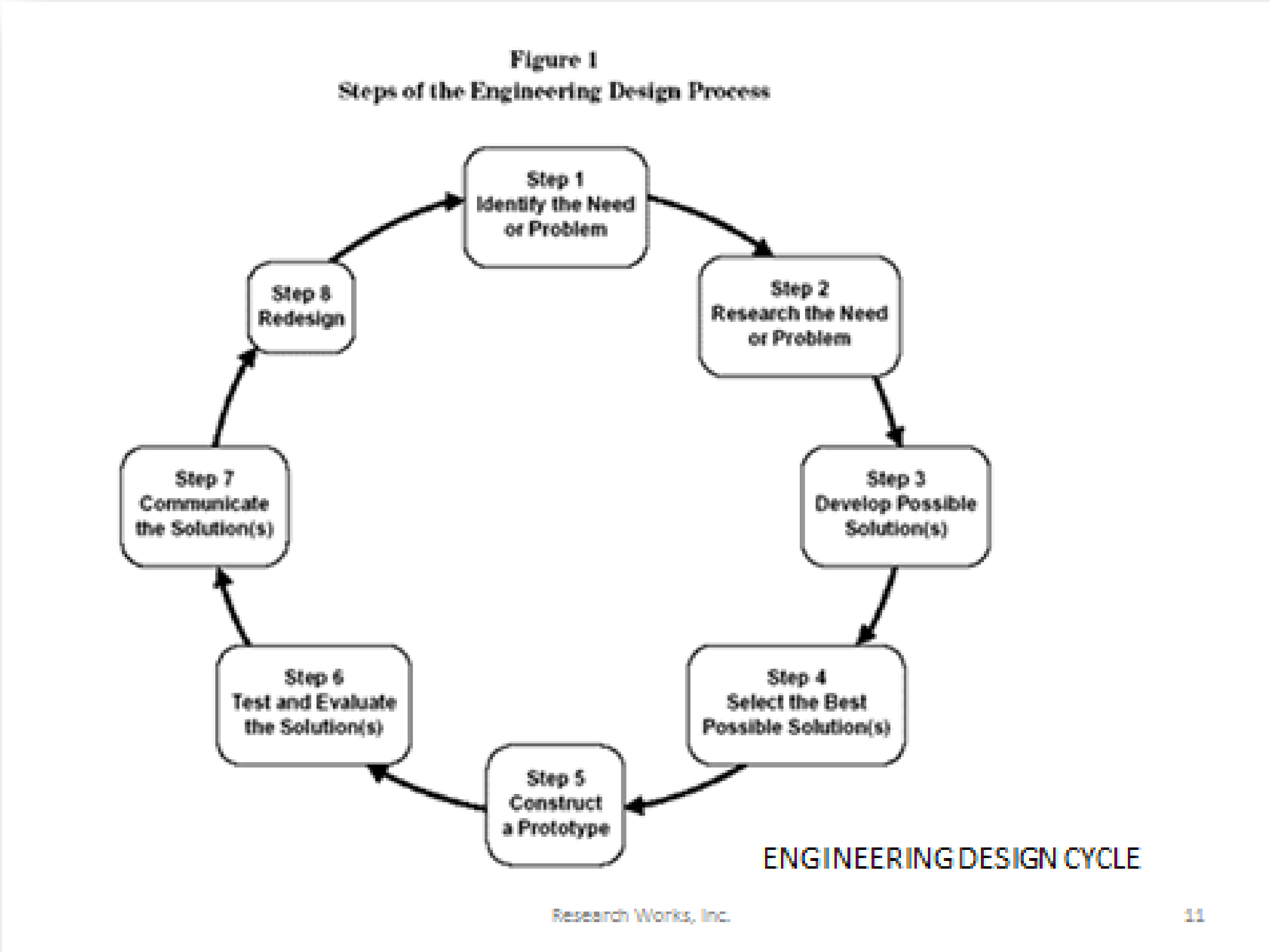
Here is where I state again that I have my opinions and prejudices and this document is meant to trigger debate. Be advised the Ph.D. concentration was in Evaluation but the degree conferred is Curriculum and Instruction. I can go really abstract on C&I (probably because the evaluation concentration was so applied) which is not what this group wants or needs. I tried to stay practical, but you are the better judge.

While some of the ideas shared in this next section are interesting, I have my doubts of how useful they are. Others I think are really promising, if yet not completely formed. My job is a literature review with discussion, so here it is. You are the expert respondents, at times I'm actually just trying to focus on the foggy bits.

This discussion draws heavily on chapters from:

Fostering Human Development Through Engineering and Technology Education, Moshe Barak and Michael Hacker (Eds.), 2011. Sense Publishers: Rotterdam/Boston/Taipei

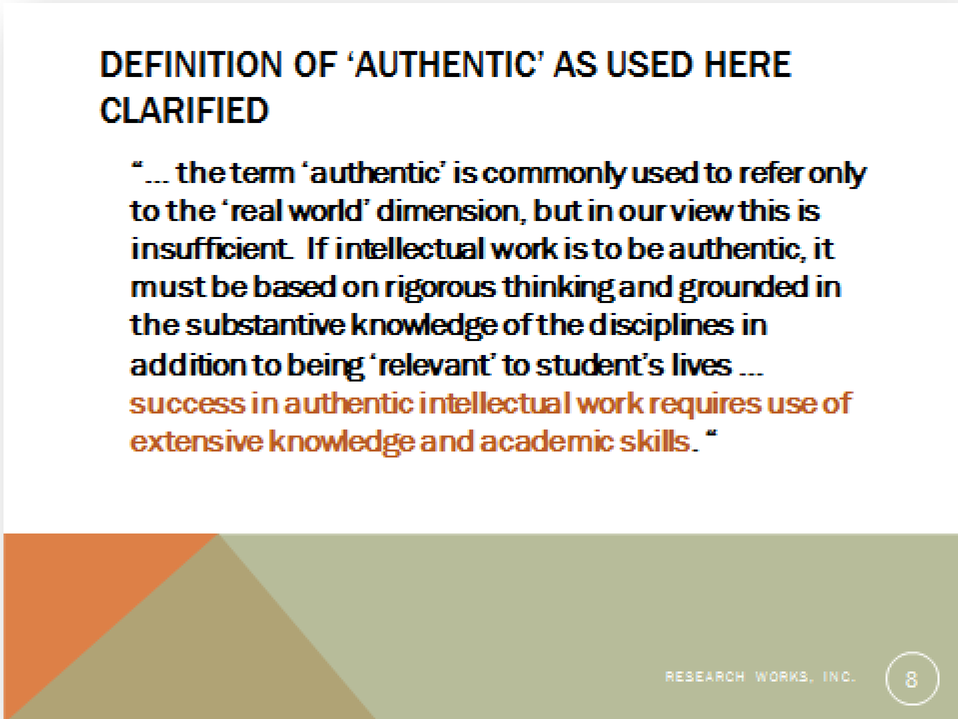
Authentic Intellectual Work from: "Authentic Instruction and Assessment: Common Standards for Rigor and Relevance in Teaching Academic Subjects", prepared for the Iowa Department of Education 2007 by Fred M. Newmann, M. Bruce King, and Dana L. Carmichael.



Along with Engineering as the 'STEM content junction', some in the US as well as most in other countries, prefer to use the Engineering Design Cycle model as a way to operationalize the functionality of the STEM content junction. The design cycle is dynamic and iterative.

Have a close look. The Steps in this process are not single activity steps, but rather sub-process titles. Teachers can identify what student activities will have to take place at each of the steps, as well as generating a description of the minimum base domain necessary to complete each sub-process, and the expected learning for each sub-process as well as for the complete process.

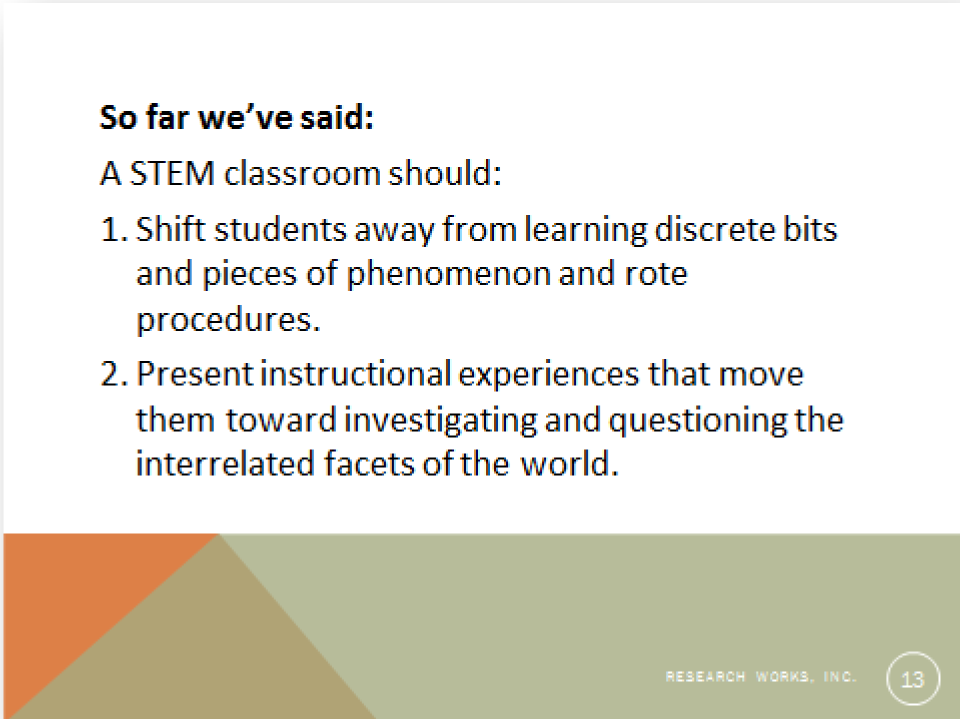
This is a good place to mention learning trajectories also known as learning pathways. All people follow their own pathway to knowledge. However, there are points on that pathway through which all travelers must pass, usually in a particular sequence. Because that is the case, it's the route taken to move from one required point to the next differs. By identifying those required points and their sequence, teachers, curriculum specialists and instructional supervisors can track the progress of students from one identified learned point to another. While used for planning forward, these trajectories/pathways are often identified by beginning at the end-point and retracing the path, a process many feel is the most efficient way to establish those common journey mileposts.



This is yet another place where the underlying assumptions of what constitutes appropriate instructional materials and how they are evaluated to be appropriate differ substantially from previous accepted practice in the US. Understanding, really understanding, the concept of 'authentic intellectual work' as the basis of identifying at least one criteria for materials in a STEM curriculum, is offered here as a possible starting point to our discussion. Hence I present what I'm thinking about it in the next paragraph.

There are broadly two reasons given for looking at a STEM focus for at least part of the K-12 curriculum: to prepare our children ultimately to qualify to engage in STEM related jobs (let's call this the focused reason); or to give all of our children the benefit of experiencing the engineered world to contribute to their general knowledge of 'things' (let's call that the broad reason).

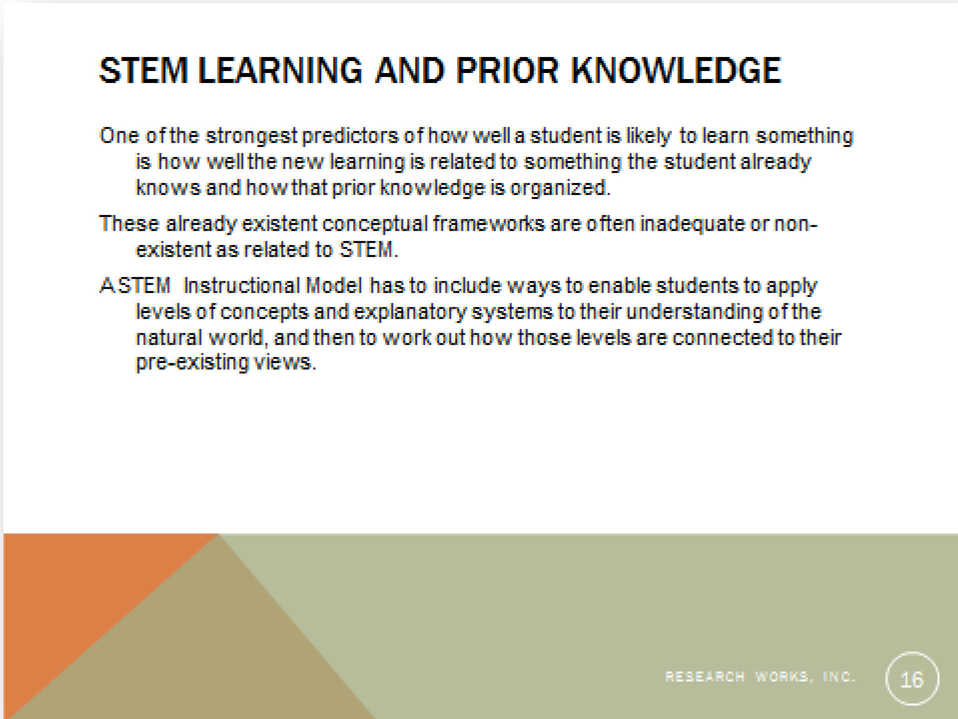
I would argue these are two sides of the same coin because the nature of productive skilled occupational as well as professional work in the 21st Century requires that all adults engaged in that work be STEM literate. Therefore, I propose that looking to researchers who step out of traditional education thinking to study what real people doing real work that is intellectual in varying degrees need to be able to understand, consider, reflect on and act on, is important. Backing into a set of indicators of what should be our expected results of instruction from the eventual workforce needs of our students should not be dismissed just because it seems too 'unacademic'.



Most writers reviewed agree with Schunn and Silk's "Learning Theories for Engineering and Technology Education", pp. 3-18, when they state that the central part of STEM is Engineering and Technology, but that all relationships within the four components must be accommodated. To prevent content-overload, educators must identify the fundamental form of the elements to be learned. In this context, skills are necessary, but not sufficient for learning.

Because they use five levels for engineering learning (borrowing the ones from mathematics), these authors clarify the difference between *procedures* and *concepts*. They note that, over time, procedures become less introspective (think about driving to work where skills information moved from being presented as facts to being presented as actions, reaching the stage of automaticity) and concepts become more introspective. Remembering that difference, the five levels they present as operating within this (and perhaps the STEM) instructional area are: procedural fluency; conceptual understanding; strategic competence; adaptive reasoning; and productive disposition.

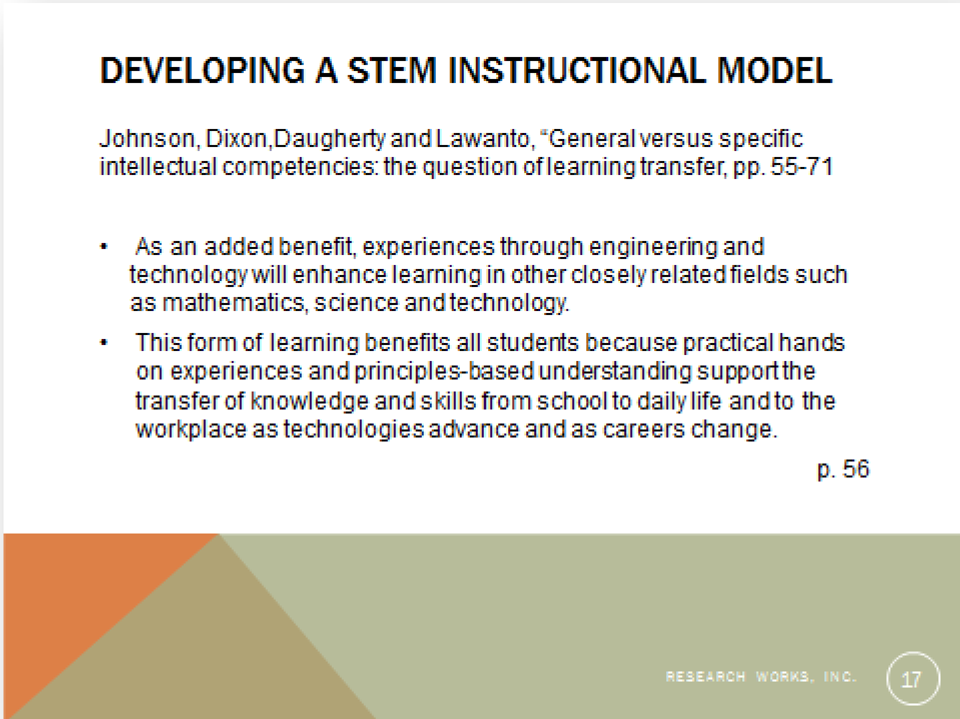
There is also information presented in this section of the cited text regarding what types of learning outcomes we should be looking for as interim indicators of student learning. Some information for our next meeting!



This slide raises the question of 'learning transfer', usually defined as the application of skills, knowledge, and/or attitudes that were learned in one situation to another learning situation (Perkins, 1992). If it works, this increases the speed of learning. Although most of us think we do this naturally, research has shown that not to be the case. Life would be less complicated if this was as easy as it sounds. Research indicates two things: context of learning environment is critical in transfer; and transfer does not occur automatically. Perhaps STEM based instruction and the looming need to deliver instruction to support the Common Core State Standards (CCSS) will facilitate teaching mathematics and science with more attention to the support of transfer of learning by all students from a very early age. As the final bullet says, if the STEM instructional model has ways to enable students to apply levels of concepts and explanatory systems to their understanding of the natural world, and then to work out how those levels are connected to their pre-existing views, there is a probability that transfer will take place more often.

If we want students to demonstrate learning transfer through project based learning using the engineering design cycle in such a way that they recognize and legitimate their own transfer of skills and knowledge our lessons have to formally include student reflection on their own learning processes. One idea is to set several problems during the year that address the intersection of multiple content areas and systems of thinking so that students can use the engineering design cycle to posit a number of possible solutions. Part of the lesson process would require them to identify and reflect on their transferred skills and knowledge.

Most importantly teachers should model this process of knowledge construction, including reflection on the referencing of prior knowledge as part of the overall learning process. Perhaps using Vygotsky's 'Zone of Proximal Development' and a gradual release of responsibility model would enhance the effectiveness of this strategy.

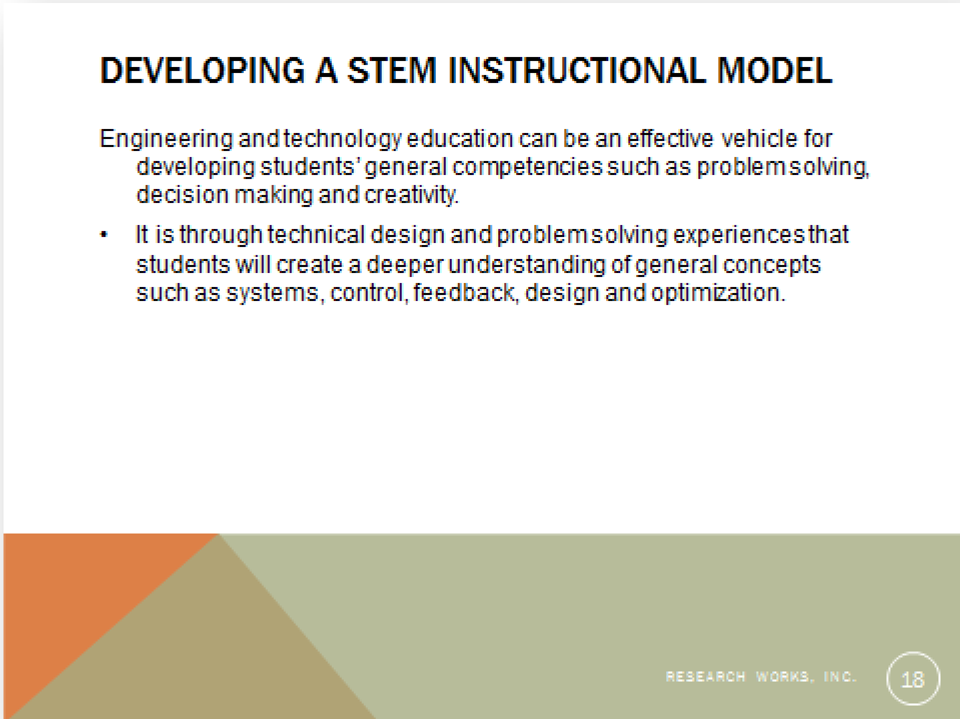


The first bullet makes the point that STEM related instruction might help with the time element of the CCSS-referenced instruction now looming on the horizon. CCSS that come to mind include those in the 'closely related fields' and in the Science and Mathematics Literacy sections of the ELA Standards, as well as the Social Studies Literacy section if the systems into which the engineered solution will be placed include the economic, political, or social systems of the Social Studies.

The second bullet emphasizes again the importance of linking learning to daily life (including authentic intellectual work) in order to support the transfer of learning.

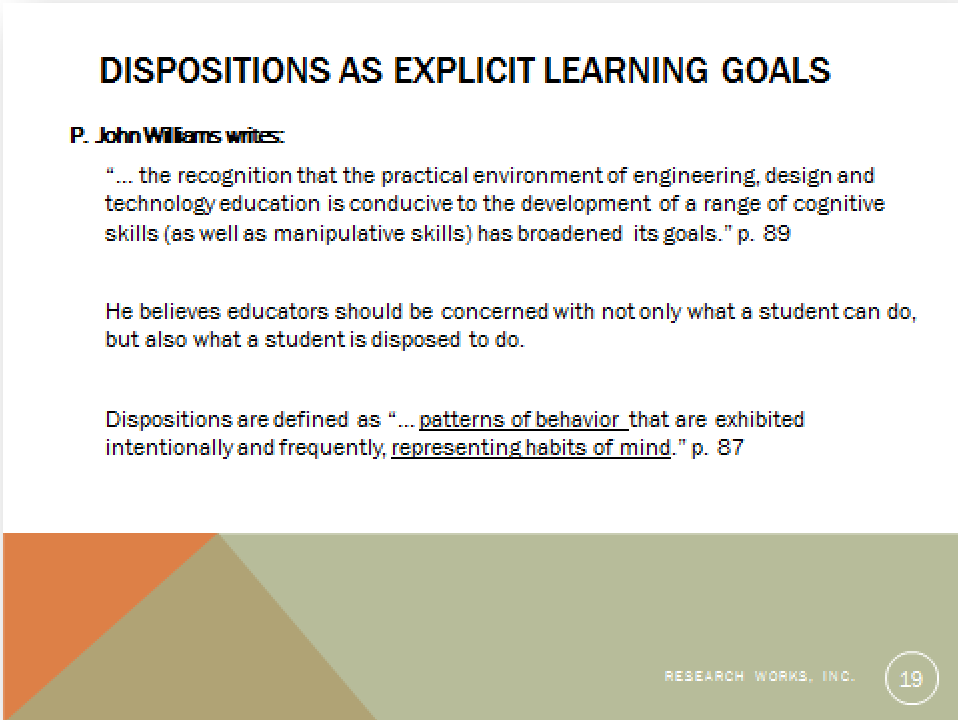
This observation presents some questions regarding present instructional practices and their applicability to this new learning environment. For example, the benefit of 'traditional' play with young children (blocks, tinkertoys, sand tables, Bio trains, etc.) gives children opportunities to practice the application engineering skills <u>but</u> does not support or require them to identify or verbalize their knowledge transfer.

> So, what language should teachers use to expand present experiences to include a fostering of learning transfer?
>
> And what language should the students use when they are constructing their schema for this transfer?



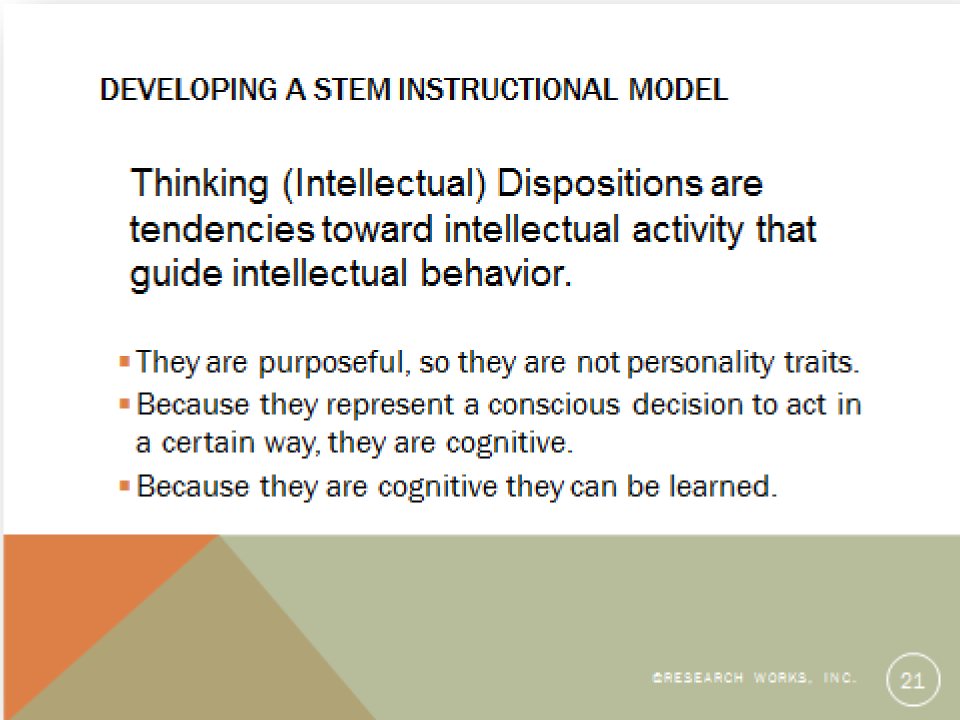
As our company evaluates a number of STEM focused projects across a spectrum of instructional environments, our team has noted some points you may find interesting. Here they are in no particular order:

1. Many teachers are very comfortable with the Inquiry Based Learning Model which they have some experience using in science in particular.
2. Many of these teachers express the Inquiry Model as appropriate to use 'when scientists have to solve problems'.
3. Problem solving in science is related to issues arising often around the practical logistics of 'doing science'.
4. Relative to their professional relationship with society, scientists are not responsible for solving the problems arising when humans need to adjust the natural world to suit their purposes. That is the professional responsibility of engineers.
5. Indeed, engineers draw heavily on scientific knowledge when addressing their type of problem, but they are not scientists. And scientists are not engineers. One profession provides rigorous knowledge and skill sets to the other, feedback on practical application of scientific knowledge by engineers informs future scientific inquiry. The two are perhaps symbiotic, but they are still not the same.
6. Clarifying this for educators is perhaps the first major hurdle to implementing STEM instruction successfully. The Engineering Design Cycle is not the Inquiry Based Learning Model. Both are contained within Project Based Learning.



So, another wrinkle on STEM related curriculum and instruction is the broadening of learning experiences in reference to 'the development of a range of cognitive skills'. P. John Williams ["Dispositions as Explicit Learning Goals for Engineering and Technology Education" in Barak and Hacker (eds). pp 89-102.]

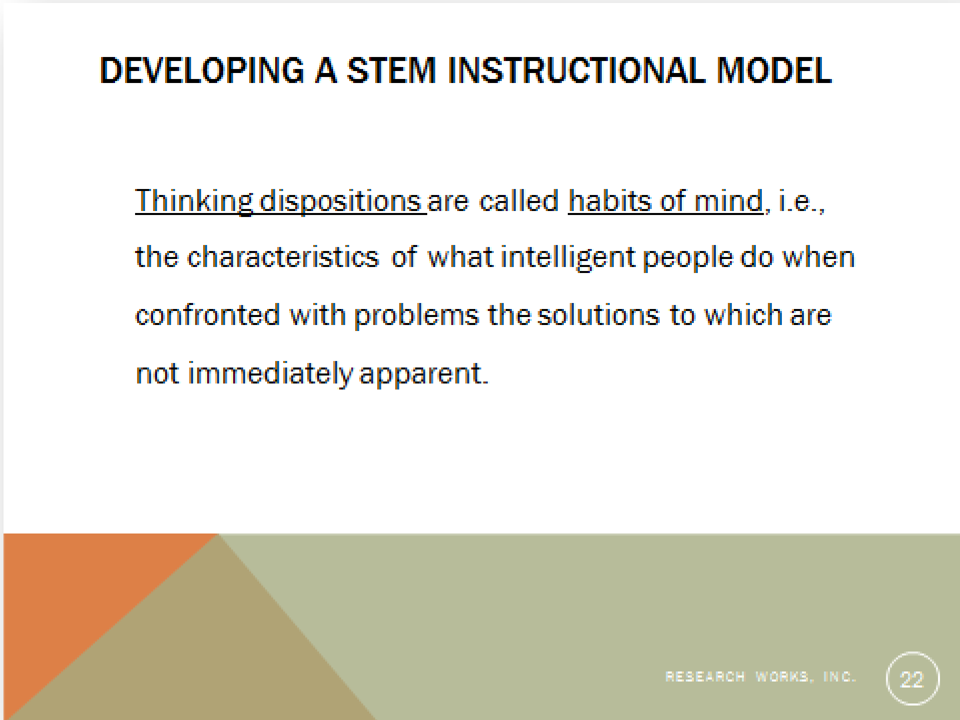
This assumption that lessons will cause learners to develop certain patterns of behavior, that they will be aware of these patterns and that they can 'turn them on and off' at will might be hard to accept. As far as I know this is an assertion that is not yet shown to be the case through any rigorous inquiry.



The same author provides this argument regarding disposition/habits of mind. As he explains, because these are developed on purpose and are additional to any personality traits, and because that development is done consciously, students can be taught about them and how to consciously develop them.

Dispositions are more commonly referenced in professional practice documents, as part of the expected outcomes of reflective practice. As this presentation I hope demonstrates, the writers on STEM are beginning to explore the expansion of reflective activities to include younger students, certainly high school age, and for some as young as upper elementary (10-11 year olds). As noted earlier, reflection on their own pre-existing knowledge and skill levels, reflection on where any previous knowledge or skills were originally learned that they are applying to their present learning, and now reflection on their intellectual processes.

In general, this heightened self- knowledge supports the more encompassing assertion that STEM related learning requires knowledge construction by learners who are meta-cognitively astute.

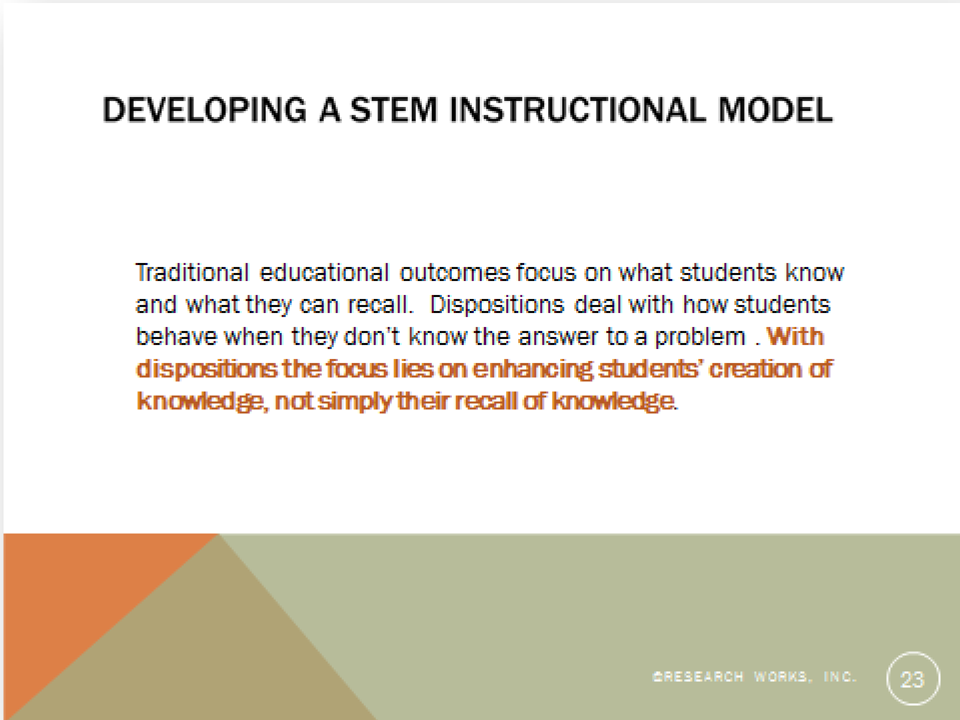


Some examples of dispositions from the same author:

- **Seek Understanding**: intellectual curiosity which also serves to anchor ideas in experience, e.g., the engineering of thinking and doing. Based on innate skepticism: building complex conceptualizations and identifying logical structures. Also a tendency to question assumptions and persist with an inquiry combined with a demand for justification.
- **Metacognitive**: relates to elements of both the self and society. The ability to reflect objectively on ones' own thinking is fundamental – but also is the ability to note the consequences on others and the environment. The process produces a high level of self-awareness, including an awareness of what is known and what is unknown, and the desire for a productive outcome.
- **Lateral Thinking**: flexible thinking with the ability to change ideas in response to the reception of new data, such as to develop multiple perceptual positions. Gives the ability to view a range of consequences and then evaluate them in terms of their goals, leading to a range of alternative strategies or solutions. However, while lateral thinkers can be macro centric and to holistically discern themes and patterns, they also understand when detailed precision is required.
- **Carefulness**: relates to a sense of mental orderliness, providing outcomes of precision and accuracy. Think ahead and be careful in both planning and execution of ideas. Needs an awareness of the criteria on which excellence is judged and a preference for excellence over expedience. This can be time consuming, taking the time to think well and act accordingly. It is also strategic – goal setting, planning and evaluation are undertaken in a calculated manner.

- **Constructive**: abstracting meaning from an experience, isolating it and applying it to a new situation. To see beyond discrete, episodic experiences and transfer past knowledge to new contexts. To foster new learning.
- **Imaginative**: entails the examination of alternative possibilities from many different perspectives. It seeks feedback and criticism and is intrinsically motivated so that education contexts have to trigger intrinsic motivations.
- **Risk-taking**: fundamental for creativity, but is moderated – not all risks are worth taking. Characterized as an exuberance to go beyond the limits.
- **Comfortable in situations where the outcome may not be clear**: able to recognize alternative perspectives and can speculate on the consequences of accepting certain assumptions. Tend to view a lack of goal achievement as a learning opportunity.
- **Make Connections**: with other people and between technologies. Other people as they operate within group work (many heads to the same problem is a good thing). Implied is an ability to accept critical feedback and consensus building through careful consideration of others' ideas. "As individuals engage in experiences encompassing the breadth of technology, they develop knowledge that enables connections to be made … (which) … enable transferability … once the connection is made, the applicability of transfer is recognized and progress is consequently facilitated." (p. 97)
- **Critical**: a frame of mind that imbues all aspects of engineering design: never without purpose; evolves from a rationale; often acting to trigger progress when working towards design solutions to problems by identifying the next logical step. In other words, it is purposeful and ultimately constructive.

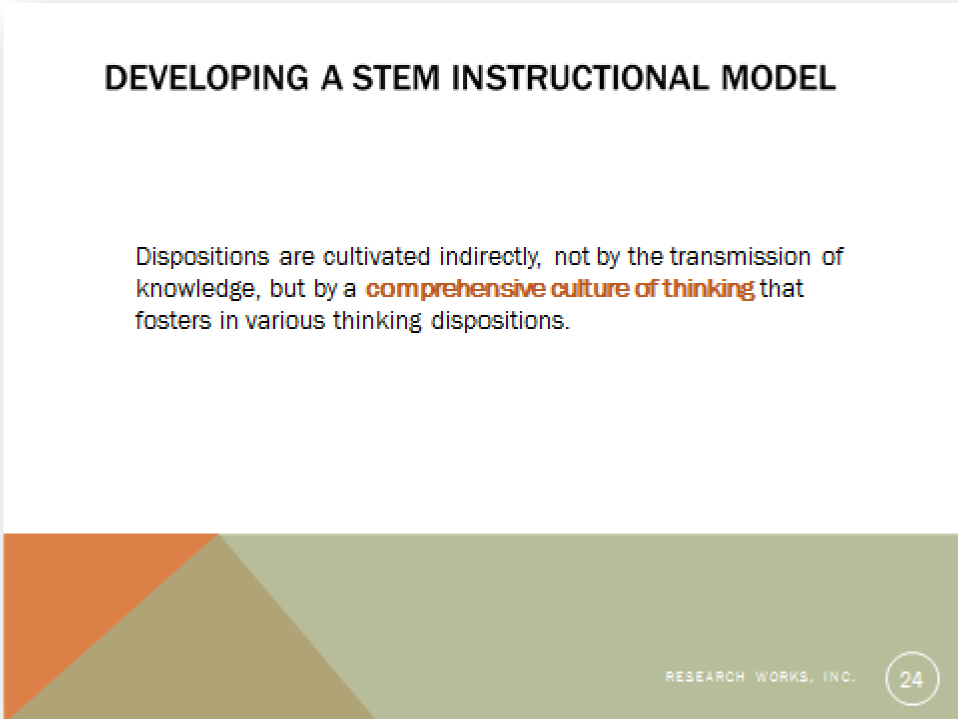
These are all inter-related and listed separately only for ease of understanding and discussion.



One example provided by the author is to consider researching to acquire information. While this is a basic skill that must be taught, the more important point is to train students to evaluate and then apply the information in an intelligent way to the problem or challenge at hand. Information for its own sake is not valued in this context. Most necessary skills are not an end in themselves, they are a means to an end.

As an example of the student behavior when operating in this 'habits of mind' environment, take the student with a critical disposition. When operating in this instructional context that student will only use it if the circumstances, context, audience, and situation indicate it is appropriate. They self-monitor on appropriateness more and more as their experience increases. Operating a disposition is therefore not a 'feeling' so that fostering dispositions is about developing student understanding and insight.

So, the components of dispositions are both the ability to use them and learning to control the inclination to do so: ability and inclination. This author argues that a classroom fostering of dispositions must address both of these, best done by having students set goals and make plans themselves in meaningful contexts.


DEVELOPING A STEM INSTRUCTIONAL MODEL
Dispositions are cultivated indirectly, not by the transmission of knowledge, but by a comprehensive culture of thinking that fosters in various thinking dispositions.
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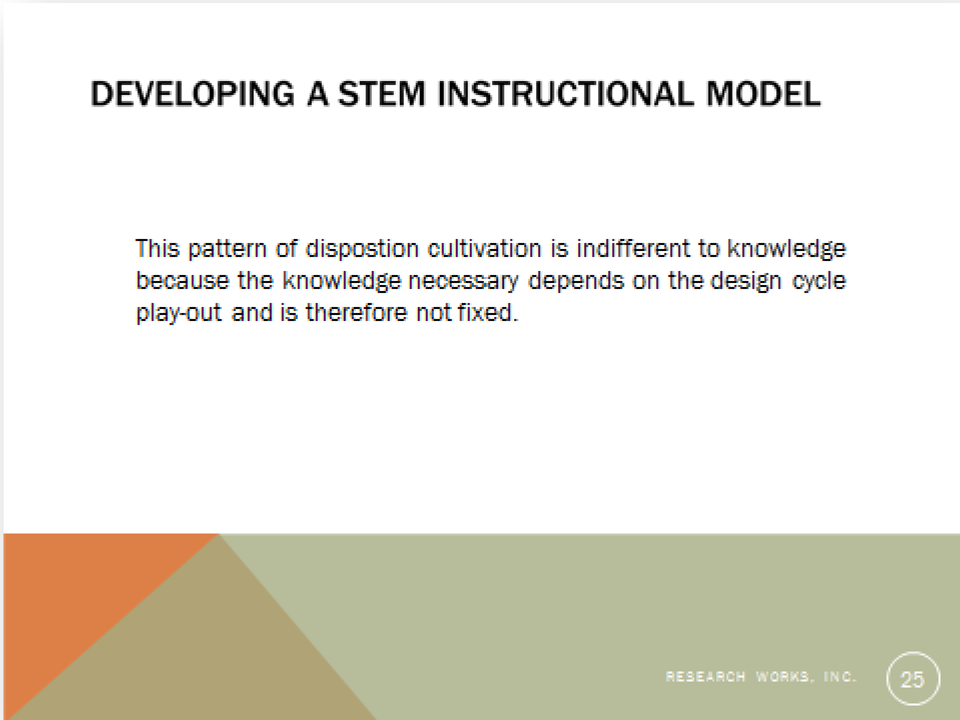
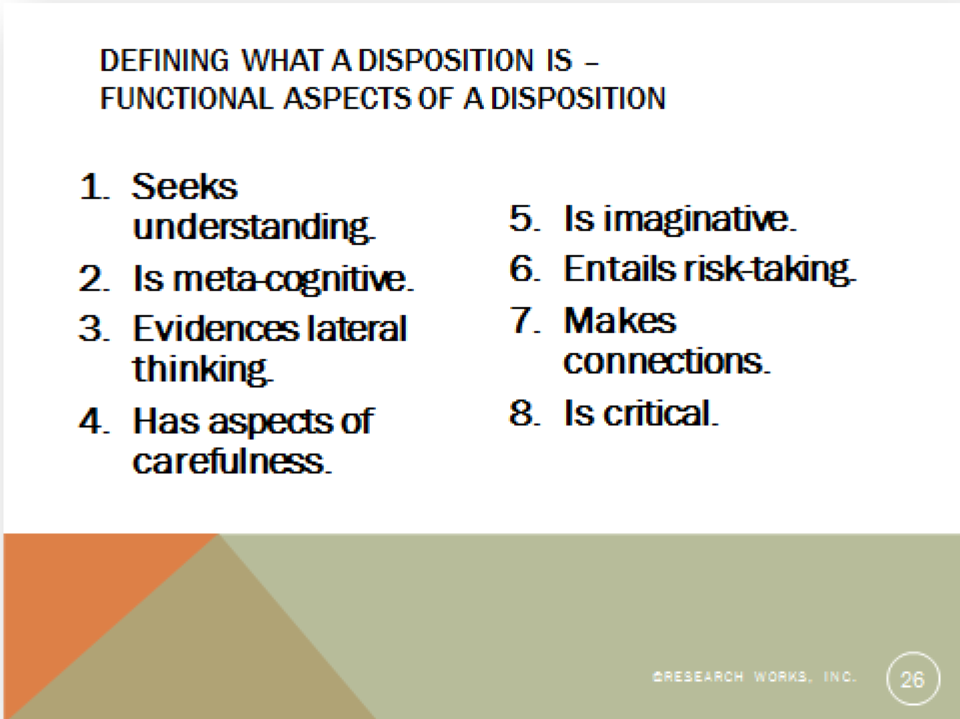


The author goes on to state that: "… the cultivation of dispositions reinstates the individual into a controlling position through the application of good thinking." (p. 98) And in addition that dispositions are summaries or combinations of many things: skills, attitudes, past experiences, influences and factual knowledge.

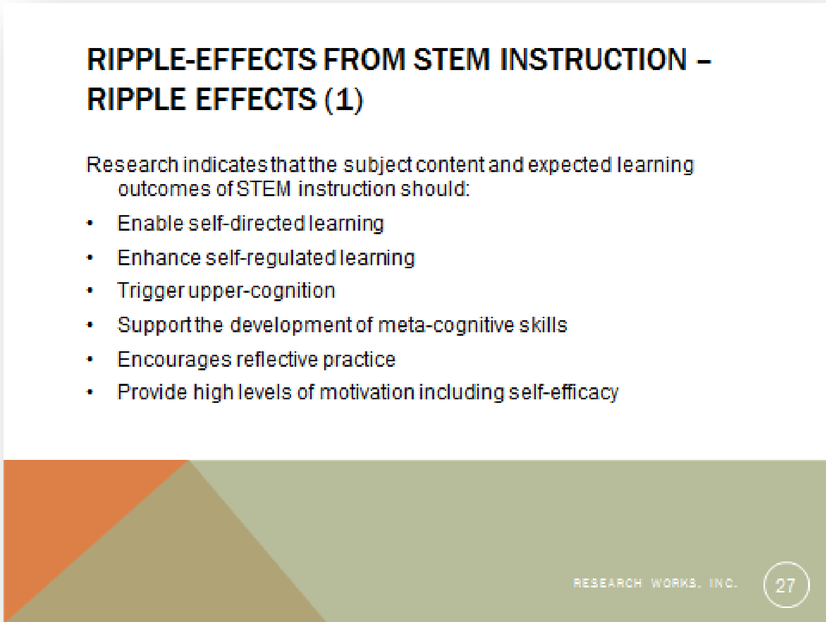
This also has a relationship to differentiation – which asks teachers to take into account that all students react to learning via their 'baggage' (his term, not mine). With the introduction of the notion of dispositions the role of the teacher is to "… encourage the application of all this baggage to new situations in a consistently intelligent and constructive manner." (p. 99)

"… learning experiences must be carefully crafted to foster the development of desirable dispositions. When students have consistent exposure to these learning experiences, dispositions develop as autonomic* habits." (p. 97) [*i.e., acting or occurring involuntarily, spontaneously]

Teachers should structure opportunities for students' reflection and deliberation, so that they develop defensible arguments based on evidence, develop listening skills that re open-minded, and predict consequences of decisions based on sound epistemologies. (p. 98)



Just a quick summary of this information from P. John Williams.



Self-directed learning is "… a process in which individuals take the initiative, with or without the help of others, in diagnosing their learning needs, formulating learning goals, identifying human and material resources, choosing and implementing appropriate learning strategies, and evaluating learning outcomes." (Knowles, 1975 in Moshe Barak, p. 35)

Self-regulated learning is the ability to control and influence one's learning processes, for example by planning, goal-setting, strategy implementation, summarizing and monitoring one's own progress.

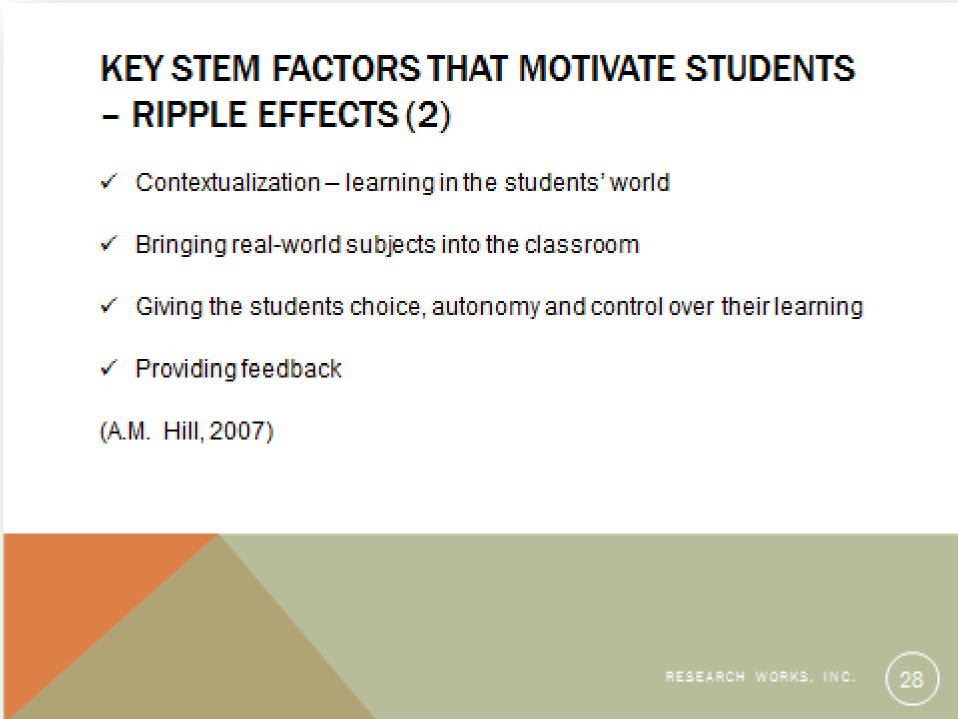
Upper cognition relates to the conscious mental processes by which knowledge is accumulated and constructed by analyzing, conclusion drawing, reasoning, synthesizing, problem-solving, assessing and creative thinking.

Meta-cognition is broadly defined as any knowledge of cognitive process that refers to monitoring or controlling any aspect of cognition. Notes that Flavell (1979) offered two types – meta-cognitive knowledge (knowledge of different strategies for different tasks, the conditions of their use, and sensitivity to their success); and meta-cognitive regulation (the use of knowable meta-cognitive strategies or sequential processes to control cognitive activities aimed at meeting a specific goal.

Reflective practice relates to the continuous process of learning from experience. It involves the individual considering critical incidents, asking questions about what we know and how we know it and 'learning to learn'.

Motivation is the internal state or condition that activates behavior and gives it direction, the desire that energizes and directs goal-oriented behavior and the influence of needs and desires on the intensity and direction of behavior. This includes self-efficacy, or a person's belief in their capability to produce designated levels of performance that exercise influence over events that affect their lives (Bandura, 1997).

Summarized from: "Fostering learning in the engineering and technology class: From content oriented instruction toward a focus on cognition, meta-cognition and motivation", Moshe Barak, pp. 35-53



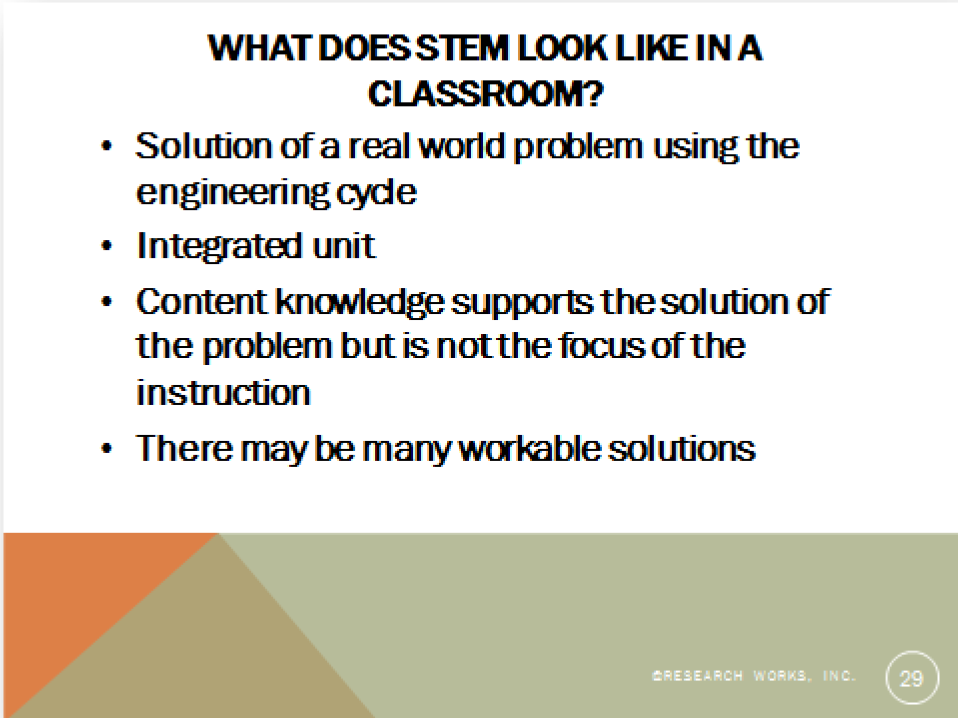
The sub-text of all the articles and chapters read for this review is that by its very nature, STEM focused curriculum has to be a curriculum where knowledge is constructed, not received. The experience of that process should then have far-reaching effect on students (and their teachers) thus creating a culture of knowledge construction as 'the way things are', not as a unit-specific and short-lived 'optional extra'.

The one area of education and systemic education reform where this fits is in the development and implementation of the Core Standards. The two sets already in operation in the US (English/Language Arts and Mathematics) signify a massive shift in the epistemological basis of the American Curriculum.

epistemology is the philosophical theory that seeks to define knowledge, distinguish its principal varieties, identify its sources, and establish its limits. Think about it, this is what we do in education every day. The varieties of knowledge most often used are: Knowledge How (Practical Knowledge); Knowledge That (Propositional Knowledge); and, sometimes Knowledge Of (only sometimes because much in Knowledge Of can also fit into the two previous varieties).

Historically, the US academic curriculum has been designed to instruct in Propositional Knowledge*, with Practical Knowledge treated as an offshoot (often of less importance). The Core Standards, and for that matter STEM instruction links the two with Knowledge That being used/applied to informing and deepening Knowledge How.

* Eventually leading to a curriculum where 'knowledge' is defined as the retrieval of factual information.


WHAT DOES STEM LOOK LIKE IN A CLASSROOM?
• Solution of a real world problem using the engineering cycle
• Integrated unit
• Content knowledge supports the solution of the problem but is not the focus of the instruction
• There may be many workable solutions
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