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Moving Beyond Active Learning to Engineering Learning: An Approach to Course Design and Enactment

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Overview

While active learning is acknowledged to “work” through numerous pair-wise studies comparing it against traditional lecture, it is important that we continue to unpack the nuances of active learning (Streveler & Menekse, 2017). This is necessary in order to ensure that courses are well designed and enacted by faculty, providing them a clearer understanding of what types of activities they should be planning so students can best master the intended learning. Having a clearer vision of the types of activities that are more efficient for achieving different learning outcomes also serves faculty developers and educational researchers as we study and support faculty in appropriately implementing active learning.

Streveler and Menekse (2017) propose two frameworks to unpack and classify active learning activities: ICAP (Chi, 2009) and KIE (Linn, 2000). When studied and more thoughtfully understood, these two frameworks provide interesting perspectives on active learning from a research perspective. However, numerous authors have noted that these frameworks have not provided clarity about what active learning is (Andrews, Leonard, Colgrove, & Kalinowski, 2011; Coolman, 2016; Prince, 2004). In this paper, we propose an alternate framework to move beyond discussions about what active learning is: Engineering Learning (Spiegel, 2016).

Engineering Learning shifts the focus from trying to identify a particular *type* of activity (e.g., discussion, interactive tasks, active learning) to the *alignment* among student learning outcomes, activities (including but not limited to active learning), and assessments. Engineering Learning achieves the goal of guiding faculty to “design instruction that matches kinds of activities to the importance and difficulty of outcomes to be achieved” (Streveler & Menekse, 2017, p. 189). Engineering Learning is based on current educational research and modeled on an engineering design framework to provide a familiar context for engineering faculty. Engineering Learning focuses faculty on student learning and on “designing” learning experiences, rather than on “covering” content or texts. Through the design process, faculty articulate and align the learning outcomes, assessments, and the tasks, as well as anticipated student backgrounds and skills. It is within the design of the tasks that active learning is unpacked, developed, and selected to align with the learning outcomes.

This paper details the process of Engineering Learning along with a case study at the Colorado School of Mines (Mines) that highlights how the process led to a more active learning course design. We also provide pair-wise data comparing results on common exams between the Engineering Learning sections to other sections (not engineered) of the same course. The Engineering Learning framework is further explored as a model to inform research and practices at other institutions.

Active Learning vs. Alignment of Tasks with Learning Outcomes

Designing instruction that aligns activities, tasks, assessments, and resources to the intended learning outcomes requires significant shifts in the ways faculty approach course design. Traditional course design follows a pattern where faculty first identify the content to cover, consider how to organize the information, and then design assessments. Activities get added as an afterthought. The content to cover is derived from a list of topics or an information textbook. The topics are divided across the length of the semester and activities are selected or designed to support the acquisition of the information from the topics. This is an old factory model that

presumes the information in each course is so unique, the only real source is the university professor. This “coverage” perspective limits the thinking about active learning during course design (Barr & Tagg, 1995; Fink, 2013; Pardue, et.al., 2005; Weinmar, 2013). In the information age, information coverage is not the primary need from most university courses, rather it is apprenticing students to the discipline; modeling expert practices; providing feedback and guidance for students to build mastery of skills including analysis, design, reporting; and other engineering practices that utilize knowledge sets, but rely more on the use and assessment of information than on the recall of information (NRC, 2012).

Similarly, when it comes to instructional approaches (enacting the course), many traditional STEM courses in higher education are still heavily dominated by lecture as the primary use of class time (Haave, Lovitt, & Weimer, 2016). Engineering, science, and mathematics require active mental engagement to master the practices and content of the disciplines. Students who have been successful in these fields often learn to tackle the content, although this frequently happens outside of the class time. Some still consider this active learning if the students are working through problems and making sense of the content outside of class time (Small, 2014). However, this is not consistent with the intended learning outcomes of many of these courses.

Expanded access to technology and media, shifts in workplace practices and needs, and the ubiquitous access to information have shifted the way people learn and what they need to learn. In conjunction with new educational research, cognitive studies, and brain research, these shifts have led to new thinking about teaching and learning (Bransford, Brown, Cocking, & National Research Council, 1999; Dweck, 2008; Morony, Kleitman, Lee, & Stankov, 2013; Resnick, Asterhan, & Clarke, 2015; Schneps, Sadler, Steinberg, & Crouse, 1989; Wiggins & McTighe, 2011). In particular, a large body of work has established that traditional lecture is significantly less effective in helping students achieve higher, cognitively demanding learning outcomes when compared to teaching that focuses on engaging students in rigorous learning activities (often referred to as “active learning”) (Bransford, Brown, & Cocking, 2000; Chi, 2009; Freeman, et al., 2014; Prince, 2004).

Given all these shifts and the common knowledge that active learning is often more effective than traditional lecture (Streveler & Menekse, 2017), faculty struggle to know what they should do in their courses. For example, we surveyed faculty to learn more about their understandings and perspectives on active learning. We had a 56% response rate from the entire Mines faculty, so had a good representation of faculty perspectives. The survey and subsequent interviews with faculty indicated that faculty knew “active learning” was something that they should be trying, but that they had little or no idea what active learning was, how to enact it, or what kinds of activities they should use to make their courses more active and to achieve the outcomes for their courses. Faculty were confused and looking for guidance on how to better design their courses.

The issue faced by our faculty of not being sure when and what kind of active learning is appropriate is mirrored in the larger literature, which seems to have focused more on the instructional enactment of active learning instead of on the course design that would lead to active learning. This led us to consider how to better frame the intent of the types of instructional reform we were hoping to achieve across campus.

A prominent approach to course design that shows significant impacts on student learning is a “backwards” design (Wiggins & McTighe, 2011). Instead of starting with the content to cover, instructors begin by clearly identifying the intended outcomes (what students will learn from the course). The outcomes then drive the selection and development of assessments. The tasks

and resources are then selected or developed to support students in achieving the outcomes. This is not unlike an engineering design process where you first consider the problem and outputs (what needs to be accomplished – outcomes), then research the issues and get client perspectives/needs, define requirements (assessments), and then begin a development process to create the solution (tasks, lessons, learning resources). The Engineering Learning model evolved from this engineering design process and educational research.

What is Engineering Learning?

Engineering Learning is an instructional design process that slows faculty down so they can focus on designing learning, moving away from the idea of covering content, and instead on becoming *learning engineers* (Simon, 1967), designers of high-quality learning environments and opportunities to achieve rigorous STEM learning outcomes. Engineering Learning uses a conventional engineering design model (Khandani, 2005) to scaffold faculty in a familiar context while they undertake the challenging task of designing and facilitating well-designed and aligned learning experiences (courses), as illustrated in figure 1.

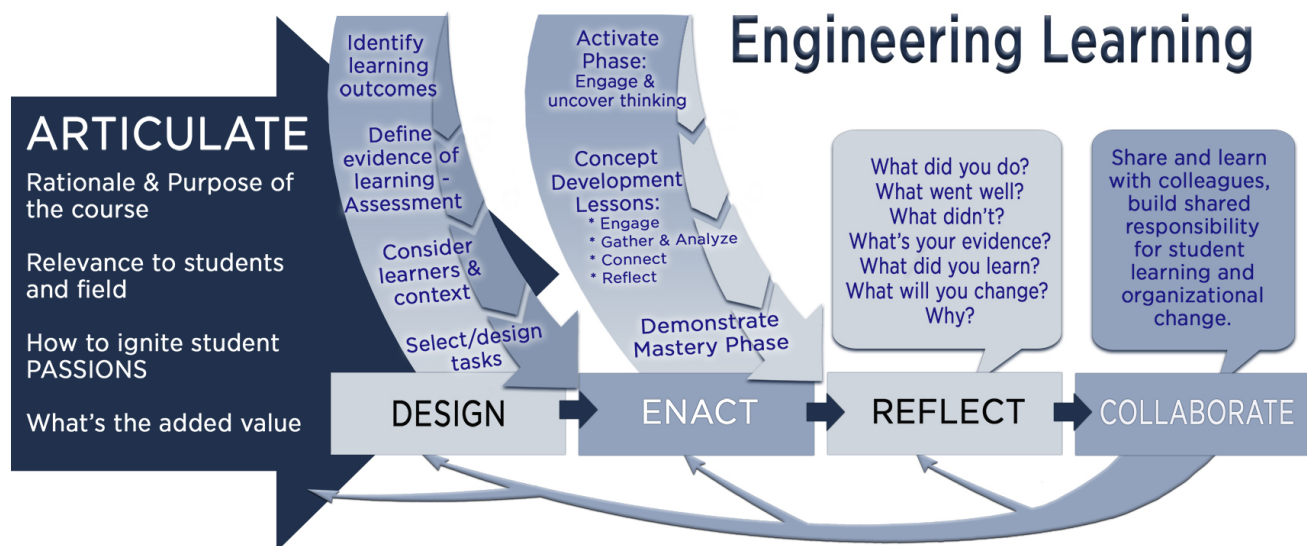


Figure 1: Engineering Learning model (Spiegel, 2016)

Engineering Learning drives significant shifts in the ways teaching and learning are approached in higher education: “the intent is to realign instruction with current research-based approaches to teaching and learning, changing student needs, and the practices and understandings wanted by industry and needed for the world of tomorrow” (Spiegel, 2016, pp. 1). The model provides a framework to analyze, design, and assess courses and learning opportunities across the design, enactment, and post-instruction phases of course implementation. The framework is broken down into five separate components: Articulate, Design, Enact, Reflect, and Collaborate.

Articulate. Engineering Learning begins by articulating the purpose and rationale for a course in a few sentences. This entails addressing four points:

1. **Rationale and Purpose of the Course:**

What is the value and overall purpose of the course? Why this course at this time for the students? How does this course connect to other courses in the sequence?

Articulate (continued)

2. **Relevance to Students and Field:**

What should students already know and be able to do related to this course content before taking the course? How will what students learn in this course help them in their further studies at Mines AND in their career? Why should this course be important to the students?

3. **How to Ignite Student Passions:**

How will this course build on students' interests and passions? Is it designed for students with specific interests and passions or does it provide opportunities for students to apply and utilize varying passions?

4. **What's the Added Value:**

What is the added value for a student to come to your class and to do the assignments? The added value is beyond what they could get by watching freely available videos, reading a textbook or online materials, or by doing some self-study? In other words, why should they pay and engage in your course.

(Spiegel, 2016)

Design. After articulating the purpose and rationale, faculty focus on writing and refining learning outcomes for a specific course. The process focuses on the level of cognitive demand or depth of knowledge (Webb, 1997) of the learning outcome. Assessments are selected or designed that are directly aligned to measure the mastery of the learning outcomes achieved by students. The assessments are refined and evaluated to ensure they are genuine measures of the outcomes.

Faculty then consider where the students might be at the start of the course and map tasks that scaffold and build students' knowledge and skills to achieve the learning outcomes. In this process, it is the *alignment* of the learning outcomes that drives the types of activities and tasks designed into a course, rather than simply picking an approach because it might be more *active* (e.g., active learning, flipped classroom, etc.). The appropriateness of the task is evaluated by comparing the learning outcome depth and action verbs with those of the tasks, rather than simply in terms of how "active" or engaging the task is.

Enact. Following the course design process, faculty enact the course using a learning cycle that is outlined in the Engineering Learning model. For each lesson or unit, students are first engaged by activating and exposing their prior knowledge of the content. This phase also provides pre-assessment data for the faculty and students to formatively assess where the students are at the beginning of the lesson or unit. The learning then digs into content and practices development, providing opportunities for students to learn about, practice, and refine their understandings and skills. The unit or lesson wraps up with a summative assessment that allows students to demonstrate their mastery of the targeted learning outcomes.

Reflect and Collaborate. Faculty working closely with the Center then come together in smaller learning communities to review course data and reflect on the course enactment and student outcomes. This leads to further refinement of the courses and becomes an iterative course improvement process.

Engineering Learning in Action

Campus trends. At the time of the writing of this paper, we have introduced the model to more than 50% (n = 160) of our faculty and have worked intensely (see <https://trefnycenter.mines.edu/learning-programs>) with about 20% (n = 50) of the faculty at Mines in using the model to revise or design courses. We have also developed tools to help assess the up-take and impact of the model. For instance, we created the Engineering Learning Observation Tool (ELCOT) (Tolnay, Spiegel, & Sherer, 2016; Sanders, Spiegel, & Sherer, 2018) to monitor shifts in classroom interactions and the alignment with the learning outcomes and course design. We are beginning to see the impact of our faculty development efforts on faculty knowledge, instructional skills, beliefs about teaching and learning, practices, and ultimately, student outcomes.

For example, in an intensive professional development program for faculty, we spend about two weeks (10 working days) on the process of articulating learning outcomes. In our analyses, we see significant changes in the syllabi of these participants, reflecting a greater emphasis on concrete, measurable, and student-centered learning outcomes. More importantly, we have observed some degree of shift in the syllabi of all, not just a subset, of the participants who completed this program.

Similarly, the focus in the Engineering Learning model on alignment when choosing tasks has led to some profound changes in course structure and content. Focusing on the alignment to learning outcomes often leads to difficult conversations with our faculty, because we all have activities and resources we use in our courses that we love, our students enjoy, and that are very engaging. However, we repeatedly find there are activities, resources, and topics that don't align to the learning outcomes of our faculty's courses, so much so that between two to four weeks of work can be eliminated. This allows more time to go more deeply into the targeted content and practices. In other cases, we find that the course is over-packed, including more learning outcomes than is realistic to expect for the number of credits (time) committed to the course. In these instances, we consider what is critical in the course, what is nice (but not required), and what should be moved to other courses. In a few instances, it was decided that a course should really be two courses. The outcomes were critical to the degree program and would best be learned across two courses. These difficult but important insights are the direct result of focusing on alignment, rather than on active learning alone.

We have gathered data across the courses the instructors have engineered. Engineering Calculus II provides an illustrative case study of the way we work with faculty around Engineering Learning and the resulting student outcomes. It is representative of the process and impacts we have seen across the faculty efforts.

Engineering Calculus II: A case study of moving beyond active learning

Calculus II is a core course at Mines. Every student is required to complete the course, so it has large enrollments each semester and a number of sections taught by different faculty. We worked closely with two experienced faculty members to redesign the course, using the Engineering Learning framework.

Initially the course design was a very traditional calculus course. The course was structured to have small coordinated sections that all used common exams. The professors lectured and demonstrated problem solving and students worked on practice problems as out-of-class work. There was limited active learning in the classroom and the outcomes achieved were lower level

(as indicated by Webb's Depth of Knowledge or Bloom's Taxonomy). The problems were focused on computation and the course was driven by topics: integration, applications, sequence/series, and vectors. The primary assessments (exams) were all designed to be easy to administer and score, and matched the practice problems. The faculty had been working to redesign the course for a few years. Their initial efforts did not utilize the Engineering Learning framework and give us a baseline comparison against courses redesigned without Engineering Learning. The initial redesign was focused on identifying content and gaps based on student performance on mid-term and final-exams. The early redesign did not lead to the changes that the faculty were seeking. Current studies are underway to further compare redesigned courses using Engineering Learning with those redesigned from other frameworks. This paper focuses on comparing redesigned sections to non-redesigned sections. Our first concern was ensuring Engineering Learning leads to positive changes in practices and outcomes.

While the intent of this course was that students learn the application of calculus, not just computational skills, the tasks and assessments were dominantly focused on computation. The instructors recognized the level of cognitive demand, outcomes, and tasks did not align with the intent of the course. The instructors shared that they wanted to revise the course based on a number of factors:

1. most importantly (per the faculty members), they wanted to move students towards higher level learning outcomes (towards application);
2. the faculty also wanted to improve student reasoning and communication skills;
3. they wanted to engage students more in the learning process;
4. there was a desire to hold students more accountable for their own learning; and
5. both were interested in trying something new and moving away from a passive lecture format.

The faculty members utilized an Engineering Learning approach to more clearly articulate the purpose of the course and then developed SMART learning outcomes that targeted four levels of practice:

1. **computation** (i.e., Perform computations with integral, sequences, series, vectors, vector-valued functions, and polar coordinates),
2. **analysis** (i.e., Construct and interpret mathematical objects integrals, sequences, series, vectors, vector-valued functions, and polar coordinates) to describe physical or mathematical quantities),
3. **reasoning** (i.e., Apply definitions and theorems to draw mathematical conclusions and justify computational results), and
4. **writing** (i.e., Communicate written mathematical arguments and statements that are complete and logically ordered, through the use of standard notation and terminology).

These outcomes were further refined and developed to have unit and session-level outcomes that built towards the course-level outcomes. With these outcomes as the grounding focus, the faculty members chose a flipped-class model to support and guide students towards mastery of these outcomes. The flipped model followed a pattern of a pre-class reading or video with a short comprehension quiz; in-class discussions, problem solving, and modeling; and follow-up writing and practice tasks as illustrated in figure 2.

The engineered course was reviewed by other faculty and Center staff who provided feedback for further refinement. The engineered course design had tight alignment between learning outcomes, assessments, and tasks/activities. The assessments included common exams that were negotiated refinements of previous assessment designs that all faculty who taught the

course agreed upon. The two faculty members worked with the Center to develop videos and online instructional materials to support the redesigned course approach.

The two faculty members who engineered the new course design piloted the redesigned course for a semester, generated and analyzed data on the course design and student outcomes, and made further refinements. The faculty gathered data to evaluate the impact of the redesign on student outcomes by comparing common exams and assignments across the varying section formats (redesigned and non-redesigned sections).

The data indicate that students in the redesigned sections were more actively engaged (e.g., developing or interpreting models or graphics, using concepts to solve, analyzing data) and class activities were more interactive (Chi, 2009) when compared to those in the non-reformed (not redesigned) sections. The classroom practices in the redesigned sections were more closely aligned to the course outcomes compared to the other sections. Not surprisingly, students in the redesigned sections outperformed students in the other sections on common exams. They scored notably higher in the application questions compared to students in the non-redesigned sections (see Table 1).

Through the process of Engineering Learning, the faculty were able to design a coherent course that actively engaged students in and out of the class time to cognitively wrestle with the content and to develop mastery of the intended skills as defined by the learning outcomes. The faculty moved past the idea of adding “active learning” to the approach of engineering learning experiences that were well designed and directly aligned to the learning outcomes. This led to higher-level tasks being enacted during class time (noted from observation data) and increases in student performance on common exams. Engineering Learning served as a framework to guide the faculty in both course design and enactment to increase well-aligned active learning and student outcomes.

Learning Outcomes (LO)		Not Redesigned	Redesigned
Enrollment (n)		172	103
LO1: Computation	Q1	68.6%	81.7%
	Q2	57.8%	77.7%
	Q12	49.4%	67.5%
LO2: Application	Q3	87.3%	95.6%
	Q11	53.6%	67.3%
	Q14	79.5%	86.9%
LO3: Reasoning	Q6	74.7%	77.5%
	Q7	56.5%	60.4%
	Q8	64.8%	82.7%

Table 1. Calculus II Data: Percentage of Students Scoring at Least a 70% on Selected Final Exam Questions by Course Redesign Type (adapted from Carney & Swanson, 2018)

6.7 (Day 1) Work

Learning Outcomes

1. Recall the special case of the definition of Work: If object a exerts a force F_{ab} on an object b in the direction of the motion as object b moves distance d then the work $W_{F_{ab}}$ exerted by object a on object b is given by $W_{F_{ab}} = (F_{ab})(d)$. Think “work = force times distance”.
2. Recall the units used for Work:

Quantity	English	Metric
Force	lb	$Newton$ or $\frac{kg \cdot m}{s^2}$
Work	$ft \cdot lb$	$joule$ or $N \cdot m$
g (gravitational constant)		$9.8 \frac{m}{s^2}$

3. Establish and evaluate the integral (or sum of integrals) we use to move a fixed object through a fixed distance such as building a tower, pumping water out of a tank, or lifting a chain over the side of a building. Use the formula $W = \int_c^d W(y)dy$ where $W(y_i)\Delta y \approx$ the work expended on the i th layer of the object over the interval $[c, d]$. For these types of problem it is crucial to slice up the object parallel to the ground in question, compute the work for each slice, and then use the integral to “add them all up.”

Before Class Student Reading: Students will read the given handout on work. In the text this roughly corresponds to the beginning of section 6.7 Physical applications (SKIPPING density and mass and beginning with Work, from the middle of page 460 (the section that says **Work**) to the top of page 462, (stopping just before the section that says **Lifting**).

Before Class (Online Review Questions):

1. What assumptions are being made in the formula **work = force · distance**? That is, in what context can we apply the formula?
2. A $20kg$ rope (coiled up tightly) is lifted 20 meters. How much work is required to move the rope? Include units in your answer.

Hook: Beginning of Class - 5 minutes: Students work in assigned groups, responding to the following questions:

1. Which of the following scenarios requires more work? Why? (First answer intuitively and then think about how to compute the work exactly if time.)
 - (a) A rope with a mass of 20 kg and a length of 20 m coiled up tightly is lifted 20 meters.
 - (b) A rope with a mass of 20 kg and a length of 20 m hangs free from a ledge and the entire rope is lifted to the ledge.

Discussion/Mini-Lecture - 20 minutes: Discuss how **work = force · distance** is applied to the (2nd) rope problem using slicing. In this case a variable distance and a constant force. Discuss units: kilograms is a mass to need to multiply by g to get a force, pounds is already a force. Complete the 2nd rope problem modeling good writing. Expectations for writing: identifying $y = 0$ and identify the force exerted by a slice and the distance travelled.

Figure 2. Calculus II lesson sequence example. (Carney & Swanson, 2018)

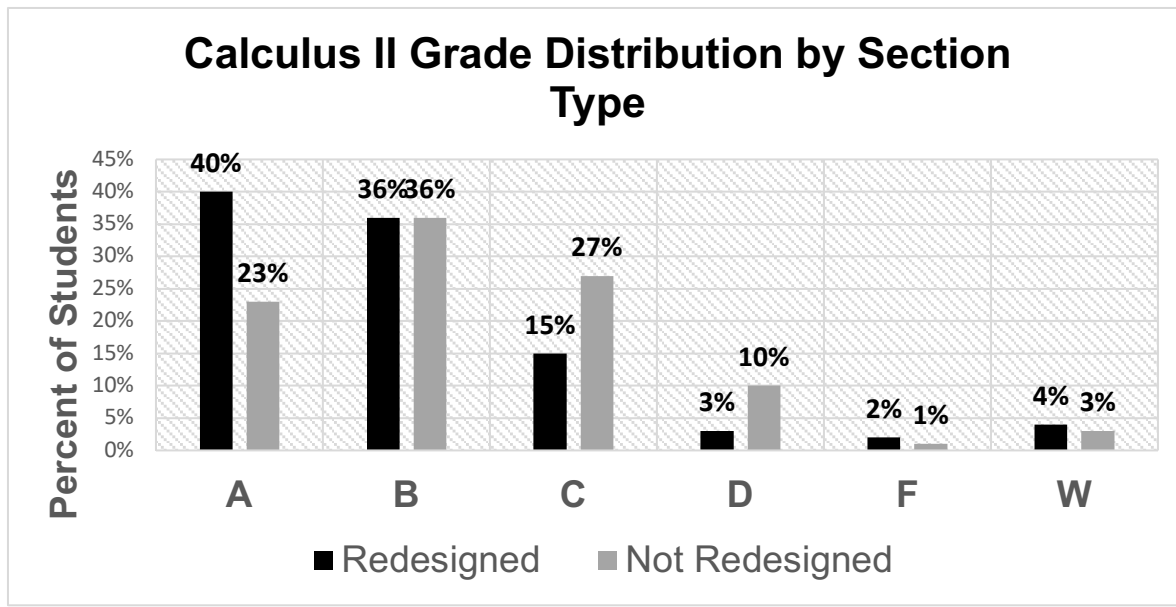


Figure 3. Calculus II Grade Distributions by Course Redesign. (adapted from Carney & Swanson, 2018)

Figure 3 illustrates the shifts in grade patterns comparing sections that were redesigned with those that were not, where all sections used common exams. Further analysis of the data is underway to explore more subtleties in the impact, as well as additional studies to examine the impact of Engineering Learning compared to sections redesigned with alternate frameworks.

Engineering Learning as a Model to Inform Research and Practice

Taken together, our preliminary, cross-campus data and rich examples like Calculus suggest that Engineering Learning is a productive framework, both from a practice and a research perspective. As a way of guiding practice, Engineering Learning leverages a familiar process (engineering design) and concrete, actionable steps. These features make the model relatively easy for faculty to adopt and enact. More importantly, the model's focus on alignment makes these enacted changes more potent than simply using more active learning would: not only are class tasks more likely to support students in achieving the course learning outcomes, but assessments are also tightly calibrated to provide measurable data for assessing student success on those outcomes.

These qualities also make the model a potent framework for guiding future research on effective classroom instructional practices. As Strevler and Menekse (2017) argue, our research needs to explore when, under what circumstances, for whom, and to what ends particular active learning strategies are effective, not whether active learning in general “works.” With its emphasis on alignment, the Engineering Learning model requires that we pay attention to the when, what, who, and why of active learning strategies under study. As such, we argue that the model has the potential to lead to precise, specific, and useful insights to inform theory and practice.

REFERENCES

- Andrews, T. M., Leonard, M. J., Colgrove, C. A., & Kalinowski, S. T. (2011). Active Learning *Not* Associated with Student Learning in a Random Sample of College Biology Courses. *CBE Life Sciences Education*, 10(4), 394–405. <http://doi.org/10.1187/cbe.11-07-0061>
- Barr, RB. & Tagg, J. (1995). From Teaching to Learning—A New Paradigm for Undergraduate Education. *Change*, Vol. 27(No. 6): 13–25.
- Bransford, J., Brown, A. L., Cocking, R. R., & National Research Council (U.S.). (1999). How people learn: Brain, mind, experience, and school. Washington, D.C: National Academy Press.
- Carney, D., & Swanson, R. (2018) Flipped Learning in Calculus II: Creating Materials that Others Can Use. Presented at American Mathematical Association’s Joint Mathematics Meeting, San Diego, CA; January 2018
- Chi, M. T. (2009). Active-constructive-interactive: A conceptual framework for differentiating learning activities. *Topics in Cognitive Science*, 1(1), 73–105.
- Coolman, A. (2016). Enabling Active Learning Through Technology. Downloaded from <https://www.smartsparrow.com/2016/07/01/enabling-active-learning-through-technology/>
- Dweck, CS (2008) *Mindset: the new psychology of success* New York : Ballantine Books
- Freeman, S., Eddy, SL., McDonough, M., Smith, MK., Okoroafor, N., Jordt, H., & Wenderoth, MP. (2014) Active learning increases student performance in science, engineering, and mathematics. *Proceedings of the National Academy of Sciences*: 2014; 111 (23); 8410-8415; published ahead of print May 12, 2014.
- Fink, L. D. (2003). *Creating significant learning experiences: An integrated approach to designing college courses*. San Francisco, Calif: Jossey-Bass.
- Haave, N., Lovitt, C., & Weimer, M. (2016). Lecture vs. Active Learning: Reframing the Conversation. Sunday Morning Plenary; Teaching Professor Conference; June 5, 2016
- Khandani, S. (2005). *ENGINEERING DESIGN PROCESS*. 1st ed. [ebook] Available at: <http://www.saylor.org/site/wp-content/uploads/2012/09/ME101-4.1-Engineering-Design-Process.pdf> [Accessed 5 January 2018].
- Linn, M. C. (2000). Designing the knowledge integration environment. *International Journal of Science Education*, 22(8), pp 781–796.
- Morony, S, Kleitman, S, Lee, YP, & Stankov, L (2013). Predicting achievement: Confidence vs self-efficacy, anxiety, and self-concept in Confucian and European countries. *International Journal of Educational Research*; Volume 58, 2013, pp 79-96
- National Research Council. 2012. *Communicating Science and Engineering Data in the Information Age*. Washington, DC: The National Academies Press. <https://doi.org/10.17226/13282>

Pardue, KT; Tagliareni, ME; Valiga, T; Davison-Price, M; & Orehowsky, S. (2005). Substantive Innovation in Nursing Education: Shifting the Emphasis from Content Coverage to Student Learning. *Nursing Education Perspectives*: January-February 2005; Volume 26: 1; pp 55-57

Resnick, LB, Asterhan, C, & Clarke, SN. (2015). *Socializing intelligence through academic talk and dialogue*. Washington, DC: American Educational Research Association

Sanders, M, Spiegel, SA, Sherer, J. (2018). Moving Beyond “Does Active Learning Work?” with the Engineering Learning Observation Protocol (ELCOT). Paper accepted for ASEE National Conference, Salt Lake City, UT. June 2018.

Schneps, MH, Sadler, PM, Steinberg, S, & Crouse, L. (1989). *A Private Universe*. Burlington, VT: Annenberg Media.

Simon, HA. (1967). The Job of a College President. *Educational Record*, Winter 1967, 48, 68-78.

Small, A. (2014). In Defense of Lecture, published in the *Chronicle of Higher Education*, May 27, 2014. Downloaded from <http://chronicle.com/article/In-Defense-of-the-Lecture/146797>

Spiegel, SA. (2016) Engineering Learning. Available at <https://trefnycenter.mines.edu/pedagogy-resources/engineered-learning/>

Streveler, R & Menekse, M. (2017). Taking a Closer Look at Active Learning. *Journal of Engineering Education*. 10.1002

Tolnay, T, Spiegel, SA, & Sherer, J. (2016). Development of the Engineering Learning Classroom Observation Tool (ELCOT). 2017 ASEE Annual Conference. New Orleans, LA. June 2017.

Webb, N. (1997). Research monograph number 6: Criteria for alignment of expectations and assessments on mathematics and science education. Washington, D.C.: CCSSO.

Weimar, M. (2013) *Learner-Centered Teaching: Five Key Changes to Practice*. 2nd ed. San Francisco: Jossey-Bass

Wiggins, GP, & McTighe, J. (2011). *The understanding by design guide to creating high-quality units*. Alexandria, VA: ASCD.