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Moving an agenda of active learning in engineering forward through a model of distributed expertise

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Moving an agenda of active learning in engineering forward through a model of distributed expertise

1.0 – Abstract

This paper aims to answer the question: *How does a model of distributed expertise move forward an agenda of active learning in engineering?* The question is motivated by the creation of a cohort of Science Engineering Education Fellows (SEEFs) distributed within the School of Engineering, and the School of Humanities and Sciences at Stanford University. SEEFs have both discipline specific and pedagogical expertise, and aim to move forward an agenda of active learning in undergraduate curricula. In this paper we will define the role of SEEFs and the model of distributed expertise, and describe examples of the application of active learning concepts to undergraduate engineering courses, including a mechanical engineering course in experimental problem solving. The common challenges of SEEFs are described, including supporting diverse engineering identities within the communities SEEFs work with, and how to measure and communicate SEEFs impact on students' learning outcomes and learning experiences. Finally the best practices SEEFs shared will be shared, including supporting long-term impact and culture change needed for a continued community of practice. Overall, by creating a distributed model of expertise, SEEFs form a community of practice focused on integrating active learning into undergraduate engineering courses to support beneficial student learning outcomes.

2.0 – Introduction – background concepts

Before exploring the description of the SEEF program at Stanford in Section 3, the two basic concepts that are key to the intentions of the program are defined. These are active learning, as the SEEFs focus on furthering active learning adoption in a variety of engineering disciplines at Stanford University, and communities of practice, which SEEFs form as a distributed team to further support the adoption of active learning within these engineering disciplines.

2.1 – What is active learning, and why promote it in engineering education?

The definition of active learning varies between academic communities and disciplines, and no single definition of active learning has been widely adopted, likely due to 'active learning' being a descriptor of a range of pedagogical approaches and methods. Defined by the founder of the Science Education Specialists program, Professor Carl Wieman, as an "interactive learning style" [1], for the purposes of this paper we follow in defining 'active learning' as:

> *Active learning: A set of teaching tools, methods, and interactive experiences that promote the active engagement of students with topics during a learning encounter.*

Active learning has been adopted for use within engineering education for its ability to facilitate student learning, shown by both comparative reviews of work in the field such as by Prince [2] and quantitative-methods based studies such as by Freeman et al [3]. It should be noted active learning can encompass collaborative and cooperative learning (group work with a common goal) [4, 5] and group-based instructional methods [6] – [10], and problem-based learning, all of which feature opportunities for students to engage with learning content in a non-passive way. As mentioned, cooperative learning is one example of active learning used in engineering education. The benefits of active learning (including cooperative and collaborative, and in contrast to competitive approaches) include maximized student learning, improved quality of students' interpersonal relationships with peers, and more positive attitudes to experiences in University, as found by Johnson et al's [11] meta-analysis of 305 studies of cooperative learning (encompassing active and collaborative learning). The social, behavioral and cognitive theories that underpin cooperative learning support students to share their motivation and work towards a common goal, and structure new knowledge by linking to existing knowledge. Another example is project-based learning, defined as self-directed and collaborative work to apply knowledge to a legitimate problem [12]. Problem based learning is commonly used as the model in capstone design courses for engineering majors, where students apply their previously gained knowledge to a final year project [13], and work in small groups to solve a problem in a self-directed manner [14].

2.2 – Models of expertise sharing

Distributed expertise within an educational setting, with its roots in Lave's situated cognition model [15], connects how cognition and learning occur in a distributed setting that includes people, activities, and cultures. The situative view of learning considers that learning and cognition during participation in activities enables students to use their underlying competencies to accomplishing authentic tasks they will face in future careers [16]. Based on Lave and Wenger's seminal work on community of practice [17], where a group of people engage in a collective process of learning through shared activities, the SEEF cohort forms a community of practice focused on integrating active learning activities into undergraduate engineering and science courses. The distributed nature of the community, with each in a different engineering discipline, is leveraged to apply and share active learning methods which support student learning. Brown et al [18] reported distributed expertise in the classroom requires that teachers should be models of intentional, self-motivated learning [19], to enable communities of students that are learning to learn, and Johri & Olds emphasized the importance of the social and cultural aspects in the process of situated learning within engineering education [20]. Both of these ideas are reflected in the community SEEFs create, sharing active learning teaching methods, resources and experiences.

3.0 – Bringing active learning & distributed expertise together: the SEEF program

In 2017, the Stanford Office of the Vice Provost for Teaching and Learning (VPTL) began collaborating with physicist and Nobel laureate Professor Carl Wieman, to create the Science & Engineering Education Fellows Program, inspired by the Carl Wieman Science Education Initiative (CWSEI) [21]. With the aim of improving introductory STEM education at Stanford University, by creating ongoing collaborations with STEM instructors, the Stanford University School of Engineering and the School of Humanities & Sciences established several SEEF positions. The program draws extensively from Wieman's expertise in active learning, being modeled after Wieman's successful Science Education Specialists program at the University of British Columbia [22].

The SEEF positions within Stanford University were established to help transform organizational and departmental culture, related to engineering education, and supporting the adoption of active learning centered pedagogy. Departments submitted proposals to the SEEF program on how SEEF positions would help support the department, with a range of goals connected to the discipline. As one example, in Mechanical Engineering the focus has been on continuing to incorporate active learning into the department's undergraduate curriculum. The SEEFs all shared the goal of working with faculty, who had committed to the program's success, to support further transition the discipline's core undergraduate courses from conventional lecture-based approaches to active learning experiences. The goal of this is to cultivate students' intellectual growth through engagement and practice, to help improve the academic success and student experience. An advantage of each department defining specific SEEF goals individually, is that this degree of separation focuses the SEEF effort on student experience and improving departmental culture.

3.1 – The SEEFs as a community of practice-distributed expertise supporting the development and support of active learning

By forming a community of practice around active learning, the SEEF community works to embed these practices into undergraduate classes to enhance students' learning, irrespective of the specific engineering discipline. By forming a community of practice across disciplines, the sharing of tried-and-tested active learning-based teaching methods helped SEEFs focus their time and effort on applying, evaluating and sharing the efficacy of such methods, rather than 'reinventing the wheel'.

Similarly, the SEEF program has distributed expertise that connects the SEEFs, the teaching methods they practice, and the culture change they bring to their disciplines and the learning occurring within that discipline, as seen in ***Figure 1***.

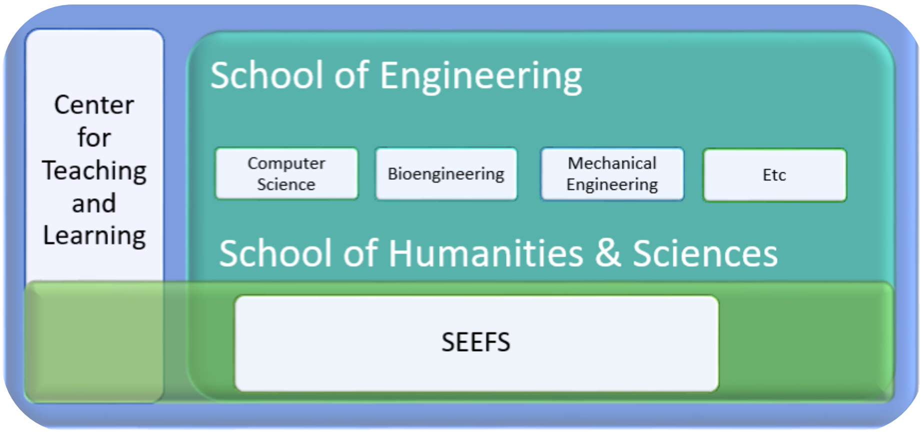

Figure 1: SEEF integration within Stanford University School of Engineering disciplines

Adopting a distributed model of expertise helps SEEFs share and use of active learning methods, which require students to take a proactive role in their own learning, embedded within their engineering discipline. The model of distributed expertise used by SEEFs is embedding each SEEF within the Stanford University School of Engineering disciplines, for the application and use of both pedagogy and discipline specific knowledge and methods, to advance an agenda of active learning within the discipline. This is termed a distributed model as each SEEF is embedded within their discipline (and brings doctoral-level knowledge of and qualification within their discipline), to deliver pedagogy focused work, as seen in ***Figure 2.*** This is in contrast to other various STEM educational roles, where the focus of study (and qualification) is mainly in education or pedagogy.

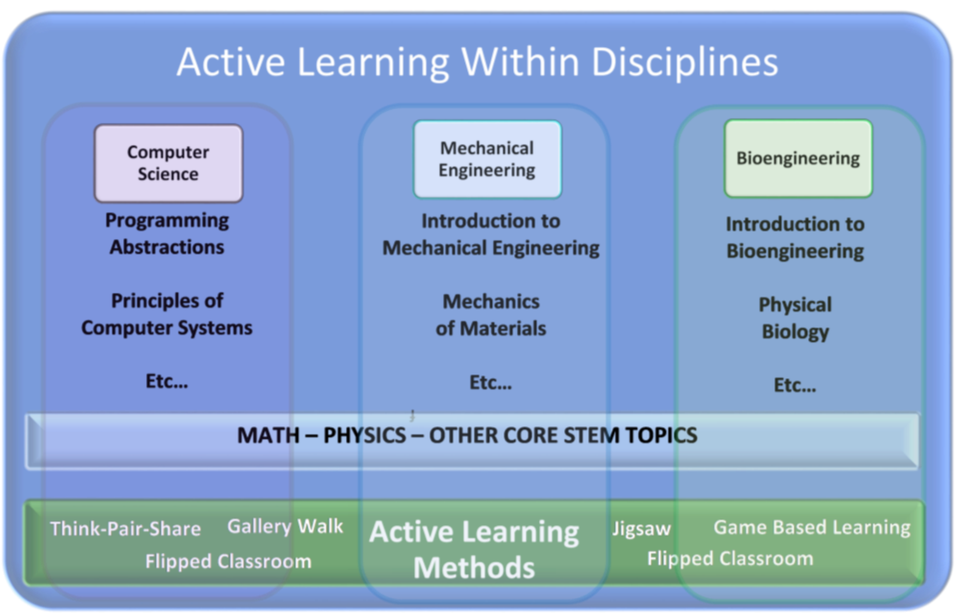

Figure 2: Representation of active learning methods applicability to a (non-exhaustive) range of STEM majors shared by SEEFs

3.2 – Research method: SEEF interviews and qualitative emergent coding

To elicit and interpret the data for this paper, standardized, open-ended interviews were conducted with six SEEF members at Stanford University, including SEEFs working within the Department of Mechanical Engineering, the Department of Bioengineering, the Department of Computer Science, in addition to individuals related to the SEEF program including the program leader within the Stanford University Center for Teaching and Learning (CTL). The interview methodology of standardized open-ended questions was chosen to design a process that facilitated interviews so that the resulting responses could be analyzed and compared [23]. A set of questions chosen to elicit responses on the SEEF role, motivations, perception and use of active learning methods within the discipline, and viewpoints on the success, challenges and best practices of SEEF work. The questions shown in ***Table 1*** were asked to all candidates as prompts, and the responses recorded as open-ended, with interviewees sharing responses both specifically in reply to the prompt and other topics they chose to share. The responses were audio recorded with the interviewees' permission, and transcribed for analysis.

A qualitative research method of emergent coding [24] was used by the first author to identify the common responses, beginning with a primary coding cycle to identify common keywords to create a codebook [25], which was then used to analyze the interviews in a secondary coding cycle to gather common codes, which were then collapsed into themes. For the purposes of this paper, codes are defined as being shorter, one word keywords such as *pedagogy*, and themes being longer, more descriptive phrases [26] such as *personal past learning experiences as a motivation to improve students' learning experience*. Once identified, these were communicated as a summative description, sometimes highlighted by individual key phrases and individual responses, to build an answer to the question posed by this paper; *how does a model of distributed expertise move forward an agenda of active learning in engineering?*

Table 1: SEEF open-ended interview questions and purpose

Open-ended Interview Questions	**Question Purpose**
How would you describe your role?	Explanation of SEEF role and motivations
What does being a SEEF mean to you?	
What are your goals (for yourself) as a SEEF?	
What are your goals (for others) as a SEEF?	
How do you define active learning?	Perception and use of active learning methods within the discipline
Is active learning important to your role?	
How do you use your discipline knowledge and pedagogy knowledge?	

Do you feel your work has moved along active learning in your discipline?	Viewpoints on the success, challenges and best practices of SEEF work
Can you give an example of a recent project?	
Do you think being an 'independent' / specific SEEP role helps you improve teaching in your discipline?	
What is something that's challenging about doing your work?	
Anything else to add?	Open-ended question

4.0 – Findings (part 1) — examples of active learning in action

All of the six SEEFs interviewed (including the first author) within the School of Engineering and the School of Humanities & Sciences at Stanford University, ranging from Bioengineering to Computer Science, termed their role as one of a consultant, irrespective of the title of the role which ranged from Lecturer to Post-doctoral Fellow, or a mix of multiple role titles. Each SEEF termed active learning differently, with three SEEF responses highlighted in ***Figure 3***, but all highlighted the importance of participation, decision- making, and reflection during learning, but all of which fit with the core pedagogical argument of active learning, which is that students learn more while participating in the process of learning [27].

"Active learning is about participating in your own learning" Dept. of Computer Science SEEF

"Active learning [is] when learners are given the opportunity to concretely grapple with a problem, situation, or question and have time to reflect and respond." – SEEF Program Manager

"Active learning is learning with students making decisions, how to make them, & reflecting on them" Dept. of Bioengineering SEEF

Figure 3: Selection of SEEF responses to defining active learning

Active learning was also regarded as a tool to enhance the reflective learning process, particularly noting how project-based learning enables students to make mistakes, get feedback, and make revisions to apply learning. The iterative process of trying, receiving feedback and making new choices, allows for instructors to help students to connect new concepts to their prior knowledge, and presents a way of thinking through a problem, not just answering it. This is a key skill that undergraduates need additional support to develop as their learning focuses less on remembering and understanding, and more towards evaluation and creation, as they progress towards more complex, less-defined problems in graduate education and engineering careers.

4.1 – Active learning pedagogy informing SEEF activities

With the SEEF program having been inspired by the Carl Wieman Science Education Initiative, SEEFs focus and use of active learning pedagogy was aligned to their self-selection by taking up a SEEF role at Stanford University. The pedagogical foundation of active learning broadly identified by SEEFs included the Lave and Wenger perspective [17], that active participation in a community of practice supports students' understanding and performance of tasks in engineering disciplines [2], and Bonwell and Eison's work that summarized literature on active learning, concluding that active learning leads to better student learning outcomes [28].

SEEFs anecdotally noted the successes of using active learning, including increased student engagement with discipline content, to increasing participation in classes, which reflects the findings of wider research into active learning. For example, Felder et al. [10] concluded active learning teaching methods are effective, such as the 'jigsaw' method previously mentioned in this paper, which was echoed by several SEEFs sharing their experiences when using this teaching method. While the topics each SEEF seeks to help undergraduates master are very different (relatively, as they all belong to Science Technology Engineering and Math (STEM) disciplines), the pedagogy they use form a common set of methods and tools used to facilitate students' learning. While this seems to be an obvious conclusion, as the SEEF program and positions are designed and focuses on teaching and learning within the School of Engineering, from the perspective of within the discipline, it is not obvious that teaching techniques would translate and be effective for each discipline. For instance, outside of common topics needed for all engineering disciplines, such as calculus, the Mechanical Engineering undergraduate curriculum courses is dissimilar and distinct from the Computer Science curriculum, including the topics, required activities, and use of technological equipment.

The individual discovery and adoption of active learning techniques by each SEEF were all through different routes, ranging from courses in pedagogy, to readings of books on pedagogical methods, or seeing methods used by other instructors. SEEFs shared common motivations of joining a career involving instruction motivated by experiences during student teaching roles, and a desire to improve teaching practices. In addition, the SEEF community referred to Barkley et al.'s handbook [29] on collaborative learning techniques provided a wealth of teaching methods, along with Godsell's sourcebook [30] which provided perspective on different methods, their implementation and evaluation, among many other sources. However common to all the SEEFs was interpreting the application of these methods to fit their discipline. For example, in Computer Science the jigsaw method was used to explore the ethics of human-computer interaction (a conceptual knowledge competency), and within Mechanical Engineering the method was used to build mastery of experimental testing (a practical skill competency).

4.2 – SEEF activities to move forward an agenda of active learning in experimental courses—a course designed around active learning.

Example 1: A SEEF being the lead in course design – With the support of the Mechanical Engineering Undergraduate Curriculum Committee, Professor Sheri Sheppard, the members of the Designing Education Laboratory, Scott Crawford, and Lester Su, a key focus for the SEEF was developing the *ME2: Experimental Problem Solving for Engineers*. In the Department of Mechanical Engineering, the need to master a wide range of math-heavy topics common to all degree majors, such as statics, dynamics, and solid mechanics (among many other topics), tends to reduce the time and resources available for ABET focused experimental and laboratory based topics and skills. This led to a SEEF focus on supporting ABET Criterion 3 (6) "an ability to develop and conduct appropriate experimentation, analyze and interpret data, and use engineering judgment to draw conclusions" [31]. The 1-unit ME2 course explores experimental design through a series of four simple but scientific experiments, and student-chosen final projects. During development, a design goal for the course was to lower barriers to experiment-based research training, by creating the course to meet the needs of a range of students and delivery methods, and designing it to be suitable for online instruction. The course was designed in a modular construction, with each unit paired with an experiment focusing on a set of experimental design concepts, enabling the course to be studied online and asynchronously. Each of the four modules focuses on learning objectives grouped around a subset of key experimental design concepts, shown in ***Table 2***.

Table 2: Example of Mechanical Engineering SEEF work to support active learning in ME2

Learning Objective	Experimental Problem Solving Concept Focus	Experiment Connection
Understand frameworks and systemic approaches to the design and execution of experiments	Goal, Hypothesis, Variables, Resources and materials, Safety, Procedures	All Experiments
Formulate experimental hypotheses and procedures		Video Game Reaction Stopwatch Experiment
Implement experimental procedures and record experimental outcomes & observations in an organized way	Qualitative Observations, Quantitative data recording	Coffee Mixing Experiment
Use statistical methods to analyze experimental data, and express the results using graphical charts	Statistics, Analysis, Interpretation of results, Charts	Assistive Technology - Predicting Running Speed Experiment
Evaluate experimental outcomes and performance, and identify factors affecting the experiment	Evaluation, Improvements, Conclusion	Materials Failure - Candy Quality Control Experiment
Communicate effectively about the results and meaning of experiments		All Experiments & Final Experiment Project

As it was anticipated that students taking the course would come from varied engineering disciplines with varied levels of expertise (freshmen through to seniors), the syllabus was created to build on core mathematical and critical thinking skills that all students have as a common basis. The course was designed to build on experimental skills students already had, and to develop mastery in applying experimental skills to the less defined problems they will face in future academic projects and careers. For example, students enter the course able to identify dependent and independent variables for an experiment, and incrementally apply these skills to ill-defined problems with many variables, which students had chosen as a final project. These final projects ranged from developing a yarn-efficient stitch for crochet, to finding the cause of edge etching in a novel silicon chip photolithography process. Each of the course's learning objectives was designed with an active learning method, fusing pedagogy gained from the SEEF community and prior pedagogical training.

During the development of the ME2 course, a '*jigsaw*' teaching method was used to explore the experimental problem solving topics to achieve the learning objectives, as shown in ***Figure 4***. Further examples of active learning methods used within the ME2 course are described in the Appendix. The Mechanical Engineering SEEF worked with the capstone course instructor to develop a '*jigsaw*' activity to experimental problem solving topics such as the hypothesis, procedures, data collection, analysis, and conclusions, and used pedagogy and discipline specific knowledge to create a legitimate, practical task for students. Each member of the capstone team 'breaks out' from the team and joins a 'topic expert' group to master a single topic (such as hypothesis writing), and then returns to their team to share and teach each other, combining knowledge together as a team to piece together a full complete solution to the full problem [32]. Capstone teams worked together to design an experiment to test the technology or device they created. The key learning point shared with the SEEF community was that jigsaw groups have to interact to a greater degree than simple a verbal share-out, as each part of the topic is interdependent on other parts of the topic (such as understanding variables to create procedures).

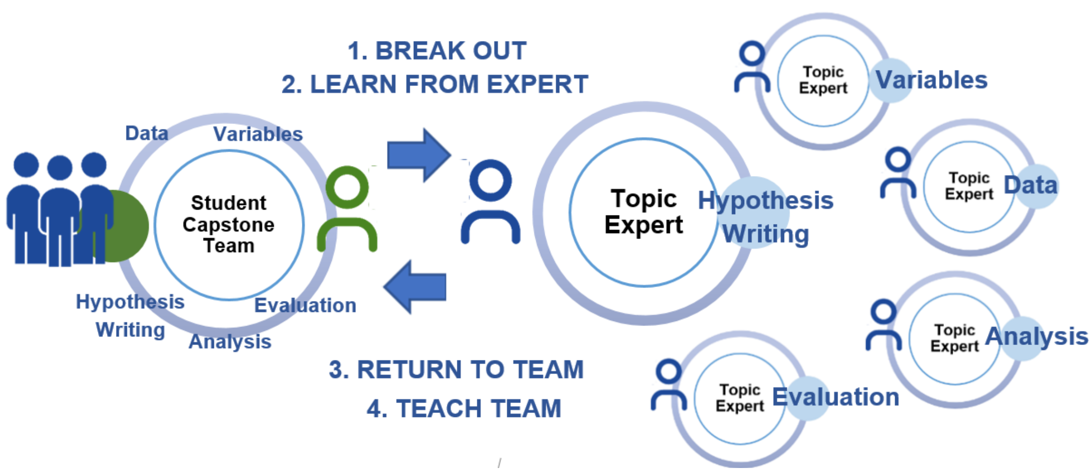

Figure 4: Jigsaw active learning method

Example 2: Adapting to online learning – During the second iteration of the course in Spring 2020, all courses at Stanford University were required to be delivered via online instruction with zero in-person contact. The course became a key point of access for students needing to fulfill science credit requirements, and was one of a small number of laboratory courses still available via online teaching in the School of Engineering. The most recent iteration of the course made use of online experimental seminars completed using video conferencing, and self-paced work such as analysis of data and report writing (which was asynchronous and could be completed at the students' individually preferred time and pace). The active learning methods previously used within physical classrooms were adapted for use in online learning, as summarized below in ***Table 3***.

Table 3: Active learning method adaptation for online instruction

Active Learning Technique	**Online Adaptation**
Jigsaw	Breakout rooms with a topic expert in each, and a team breakout room and shared document to apply learning
Think-Pair-Share	Stopwatch animations to keep track of 'think' time, and student-to-student chat functions to discuss as a pair, followed by sharing to the whole class
Gallery Walk	Viewing a series of shared screens with one-slide presentations
Muddiest Point	Polling functions in video conferences or online learning tools

4.3 – SEEF activities to move forward an agenda of active learning in experimental courses—integration into existing courses

Within the Department of Bioengineering and the Department of Computer Science at Stanford University, the incorporation of active learning into undergraduate curricula has included the addition of active teaching methods to courses predominated by 'talk and chalk', such as:

- Short quizzes to assess learning on a weekly basis, to support the use of pre-reading
- Two-stage problem sets for midterm assessments, where problem sets are completed, graded with feedback about errors or knowledge gaps, and then students reflect on feedback and attempt to improve their answers. This to enable students to reflect on their answers and engage with feedback, rather than moving on without addressing knowledge gaps.
- Developing and instructing additional training in active learning teaching methods for departmental teaching assistants, initially as a discrete course, and then incorporated as a mandatory training courses for student employees in Bioengineering.
- Using 'scaffolding', using instructional plans to lead the students from what they already know, such as using prompts, questioning, or cue cards [33], to form a deeper understanding of new material [34] with a fading level of instructor support.

- Implementing ‘exit tickets’, an end of class short task to reflect on learning, such as students noting what was most valuable, and what they are still confused on, which then becomes a teaching focus [35]
- Integration of diversity and inclusion within engineering topics, in the context of encouraging positive course climates and the development of students’ engineering identity. For example, in the Department of Computer Science, the discipline of Computer Human Interaction has a focus on both technical and wider skills needed to master both the design of computer technology and the interaction between humans (the users) and computers. As part of this curriculum ethics is embedded into each topic, and due to number of times the ethics-related analysis codes were referred to by the SEEF, it was found to be a key focus of the SEEF in the discipline.

5.0 – Findings (part 2) — common themes

5.1 – SEEF challenges expressed in SEEF interviews

During interviews some common themes with experiences and challenges related to engineering identity and organizational culture became evident during analysis, and are described below.

Importance of diverse engineering identities – With five of the six interviewed SEEFs self-identifying with a female engineer identity, the importance of exampling diversity in engineering instruction was shared as a theme in the SEEF interviews. This was both in terms of their identity and role within their department, and for supporting diversity by providing diversity in the instruction staff that students experience. Within Mechanical Engineering, out of the eight academic staff (i.e., teaching but not tenured or tenure-line) currently listed on the departmental website, none are women. Similarly, in Bioengineering, none of the non-faculty teaching staff listed on the website are female. This can lead to a delegitimizing of the academic purpose and authority of SEEFs due to unintended gender bias, and less emphasis on the organizational culture capital (the shared sense of identity, norms, values and trust) and role models needed for undergraduate students to develop an engineering identity. This includes students seeing themselves as a future educators or in an academic role such as a faculty member, which is a key aspect of supporting diversity within the undergraduate population [36], with 41 percent of the 1,525 students within the School of Engineering identifying as female [37].

Measuring and externalizing impact – A common theme identified by SEEFs was the challenge of measuring impact, and communicating this to both stakeholders and the wider academic community at Stanford University. Defining impact was also inexact, with varied definitions and methods of measurement, ranging from highly quantitative, such as the number of courses SEEFs interface or consult on, to highly qualitative, such as anecdotes from students. Understanding SEEF impact is also key to communicating the value of the activities and program to faulty, support staff and students within the discipline. In addition, it is important to express this value in a way that connects the SEEF activities to the benefits of active learning methods, such as better student learning outcomes [28].

One unanticipated issue that occurred due each department defining more specific additional goals individually (despite this being well designed and tailored to the discipline's needs), was that proposals lacked a focus on implementation. As there was less standardization, how the goals would be achieved and measured was less well described than the goals themselves. This became important as both the goals, and how they would be implemented, are key details needed to support the SEEF role and assess success and improvements. Both the goals and the implementation steps also needed to be further defined to deal with unanticipated challenges experienced, by providing a metric to track and analyze progress. This included a lack of connection to stakeholders within disciplines, or challenges in solving discipline-specific needs that resulted in roadblocks to the SEEFs' goals. The solution to this was found by forming a SEEF community, with each SEEF sharing the approaches, methods, metrics and experiences of working towards their discipline specific goals, creating common 'logic models' to meet goals, experimenting with various active learning methods or activities, and assessing the impact or change. This helped develop a common set of terminology to express the goals, and also provided an informal method to capture and support SEEF progress.

5.2 – SEEF-identified best practices

Supporting communities of practice – Creating a community of practice of SEEFs, instructors, administrators, student employees and other teaching-focused roles is a key part of creating lasting organizational change through the SEEF program, due to the limited terms of the SEEF roles. Linking SEEFs into existing communities focused on teaching within an organization, such as within Stanford University's CTL organization, also helps connect and create lasting archives and resources for teaching and learning.

Supporting long-term impact – SEEFs creating impact, including integrating active learning into the undergraduate curriculums in their respective discipline, is dependent on both the continued presence of a SEEF role and the support from faculty and administrators to support innovations and changes. This is best accomplished from within a discipline, where the specific learning topics and organization culture of each discipline is best understood. The documentation of SEEF activities and observations of what kinds of teaching and learning practices are happening in the department can also contribute both to immediate, short-term changes and refinements as well as long-term impact. By being embedded within departments, and participating in departmental committees and activities, SEEFs also acquire a deeper understanding of the culture of the department and be a resource to support change and innovation in teaching and learning within it. The longevity of the impact SEEFs create, and the organizational and learning culture changes they make, could be extended by creating longer-term roles and disambiguating the roles from post-doctoral positions which are short term by nature. This would also provide longer-term support within departments for developing and adding to the teaching and learning expertise that is unique to each engineering discipline. Providing information and support for SEEFs to evaluate their work and impacts, is also a key part of communicating and sharing the motivations and changes SEEFs create through their work.

Supporting culture change – SEEFs expressed that creating organizational change is enabled by changing the culture of the faculty, staff and students the SEEFs work with – the best practice for overcoming the inertia or resistance to change is to communicate the SEEF roles as one of a consultant, offering the ideas, time and resources to integrate active learning into undergraduate courses. This addresses the common barriers SEEFs expressed, including instructors' lack of time and resources to integrate active learning into undergraduate courses. Communicating SEEF activities and outcomes is critical to the sharing and adoption of active learning, and also provides a connection point for the wider academic community to connect with SEEF work, and shares effective programs and activities with other organizations. A best practice of SEEFs can be to help mentor members of the academic community, including students, helping encourage a community focus on the active learning and improving learning experiences in each department.

6.0 – Conclusions and recommendations

This paper aimed to answer the question of how a model of distributed expertise, such as the SEEF program at Stanford University, moves forward an agenda of active learning in engineering. The model of distributed expertise means SEEFs are embedded within Stanford University School of Engineering and School of Humanities disciplines, and apply both pedagogy and discipline specific knowledge and methods. A qualitative research methodology was used of standardized, open-ended interviews with six SEEFs in the School of Engineering and School of Humanities, and emergent coding cycles used to identify common codes and themes. The interview questions prompted responses to explore the SEEF role, motivations, perception and use of active learning methods within the discipline, and viewpoints on the success, challenges and best practices of SEEF work. SEEFs shared common motivations of joining a career involving instruction from experiences during student teaching roles and a desire to improve teaching practices, including adopting active learning methods that promote students learning outcomes. An example of SEEF work in Mechanical Engineering was described, with the development of a course to support experimental research training designed around active learning. The best practices for distributed expertise models shared by SEEFs included promoting diverse engineering identities, departmental support and interaction with SEEFs, supporting continued longevity of the SEEF program, and fostering community.

The challenge of measuring SEEF impact on pedagogy and organizational culture, and communicating this in an understandable way to both stakeholders and the wider academic community at Stanford University, was a common challenge to SEEFs. Opportunities to better meet this challenge could include expanding impact (and potentially ways to measure it) by increasing connections and knowledge sharing between student employees and SEEFs. As teaching assistants and other student employees tend to have greater contact time with students than instructional staff, this provides the opportunity for SEEFs to further impact students' learning experiences. This could also provide a way for students who are interested in teaching as a career to create connections and connect to a pathway into instruction, as during interviews some SEEFs noted they became interested in teaching as a career path, due to and during experiences of being student employees in instructional roles such as teaching assistants.

To continue to support the importance of expanding diversity in engineering instruction, the program and discipline that support SEEFs should increase focus on SEEFs engineering identity within their department, and be encouraged to engage and celebrate SEEF diversity. This includes supporting diversity by encouraging diversity in the instructional staff that students experience, and within the wider discipline. This could be supported by increasing efforts to diversify the non-research teaching staff within the School of Engineering, having 17 percent faculty female professors [38], and strengthening connections with non-research teaching staff (including student employees), including allowing all SEEFs to provide instruction which is currently not the case in all departments. Additionally, building social capital (the shared sense of identity, norms, values and trust that forms organizational culture) within SEEFs disciplines, was identified as being part of supporting SEEFs efficacy within their role, and could provide a way to make stronger connections between students, staff and faculty.

Being a distributed group, the importance of building and working as a community of practice is a cornerstone to the continued success of the SEEF program. Sharing information and practices is a key part of this, and the SEEF program could benefit from more pathways and connections to existing pedagogical training courses housed within the Graduate School of Education, CTL, and other various departments, to learn about and help share examples of their use and adaptation to each discipline. Since each discipline interprets these teaching methods differently, sharing these perspectives could generate more opportunities to integrate these methods into courses. Currently this need is being met by the weekly SEEF meetup arranged by the CTL, however the informal nature of the meetings, and lack of structured recording of the learning shared by attending SEEFs results in an organic diffusion of knowledge between SEEFs. This also highlights a gap in the continuity planning for SEEFs, and a 'bottleneck' in the flow of information from SEEFs to other instructional staff (including faculty, lecturers, and student employees, and others) within their departments, as a repository of SEEF learning could be used by future SEEFs or other instructional staff within Stanford University.

Lastly, while the pedagogical value and benefits of SEEFs supporting active learning within their disciplines is clear, by working as a cohort using a distributed model of expertise, SEEFs have the opportunity to bridge gaps between faculty, instructors, student employees, other support staff, and students. These valuable channels of sharing and developing active learning teaching methods and cultural values enables SEEFs to innovate on pedagogy as a community of practice, and focus on improving student experience and learning, while supporting the continued improvement of teaching and learning at Stanford University.

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Appendix – active learning methods

'*Think-Pair-Share*' *to connect to prior knowledge of hypothesis design* – The '*Think-Pair-Share*' active learning method, which helps students recall prior knowledge, organize their ideas (both in their own minds, and in a wider group context), and share thoughts and ideas with peers. The method, shown in ***Figure 5*** was used for students in the SEEF-designed *ME2: Experimental Problem Solving for Engineers* course to explore each topic in experiment design, including hypothesis design. A question was posed by the instructor: "What makes a good hypothesis?" Students thought individually about the question for a few minutes, paired up with a peer to discuss the key elements of a hypothesis, and then shared with the entire class, to develop a group understanding and application of a hypothesis. This method helped meet the needs of students with various levels of ability, and frame the learning objective and associated knowledge in terms of the students' understanding, which is helpful for classes that have a mix of freshmen through to seniors.

Figure 5: Think-Pair-Share active learning method used within the ME2: Experimental Problem Solving for Engineers course

'Gallery Walk' to learn experimental outcomes communication – The final two weeks of the ME2 course was dedicated to students applying their knowledge of the key experimental concepts (such as hypothesis, procedures, data collection, analysis, and conclusions), to answer a research question chosen by the student. Students were encouraged to explore topics generated from their curiosity, leading to projects ranging from exploring the most yarn-efficient stitch for crochet, to finding the cause of edge etching in a novel silicon chip photolithography process. Students presented a one-slide summary of their project (including hypothesis, experiment design, and conclusions, etc.), in the format of a one slide '*Gallery Walk*' where each project slide was physically located around the room as shown in ***Figure 6***. This discussion technique helped students be actively engaged as they considered a series of projects, and worked in small groups to consider the concepts, address their own knowledge gaps, and discuss experimental design improvements. It also created a sense of learning community within the class, as student feedback showed the one slide format helped the assignment feel like an obtainable goal, and students developed learning confidence while sharing their projects with their peers.

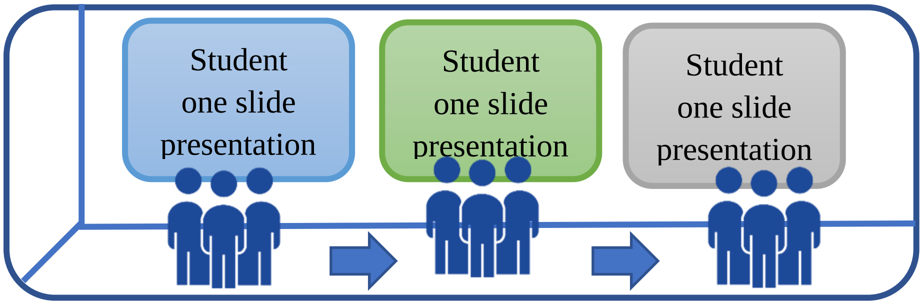

Figure 6: Gallery Walk active learning method used within the ME2: Experimental Problem Solving for Engineers course

'Muddiest Point' to assess learning objectives – Assessment in the *ME2: Experimental Problem Solving for Engineers* course also provided the opportunity to integrate active learning methods which helped create better learning experiences. The 'muddiest point' method assesses the common well understood learning points, and least understood points for an assignment, as a group. The resulting positive and negative feedback was shared with students during reflection sessions, and discussed as a group to address knowledge gaps.