122nd ASEE Annual Conference & Exposition
June 14 - 17, 2015
Seattle, WA
Making Value for Society
Paper ID #13097

Mapping the Spread of Collaborative Learning Methods in Gateway STEM Courses via Communities of Practice

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1. Introduction

While national-level calls to improve engineering education have persisted since World War II, these calls have recently shifted to advocating for the adoption of teaching methods and pedagogies grounded in the education research literature[6]. Despite these calls, the adoption of Research-Based Instructional Strategies (RBIS) has remained slow, with faculty openly resisting adoption or failing to sustain adoption after trying RBIS[1;5]. Research has amply demonstrated that there are numerous barriers to change such as faculty incentive structures, lack of time, conflicting identities, and unmet expectations[2;5]. While looking at the barriers to change provides one part of the explanation for how to create change, looking for "bright spots" of change, and analyzing them, provides an alternate approach for stimulating change[8].

Bright spots[8] are stories of successful change that happened precisely in the contexts that have been historically resistant. Critically, these bright spots are achieved without changing much about the current existing culture or conditions.

Research-intensive institutions are one context in which change in teaching practices is particularly difficult. Tenure and promotion procedures elevate research above teaching, creating time, identity, cultural, and structural barriers to the adoption of RBIS[2]. A bright spot of change, then, leads to the adoption of RBIS without changing tenure and promotion requirements or hiring practices.

At the University of Illinois at Urbana-Champaign, we have recently identified one such bright spot: the rapid adoption of an RBIS, namely context-rich collaborative problem solving[10], across five departments and ten courses in three years. The adoption of this RBIS has happened within the traditional tenure and promotion context, engaging both tenure-track faculty and lecturers. Adoption of this RBIS has also occurred at a high level of fidelity with courses and instructors sharing policies and best practices.

This paper is a preliminary analysis to better understand how this bright spot was formed. The paper begins by describing the change effort that precipitated the change followed by the story of how the RBIS spread between departments and courses. We then provide a critical examination of the change according to two perspectives: diffusion of innovations (change theory perspective) and communities of practice (education theory perspective).

2. The Strategic Instructional Initiative Program

In 2012, the Strategic Instructional Initiative Program (SIIP)[3] was created to promote the reformation of core, large-enrollment courses across the College of Engineering. Faculty were given full autonomy to propose course and curriculum reforms that they would pursue through the initiative, but faculty needed to create teams of at least three faculty and instructors (two of which had to be tenure track) to champion and sustain the reform efforts. These teams have since come to be known as Communities of Practice (CoPs)[14;15] to emphasize the importance of creating shared vision and purpose among the team members.

SIIP began with five CoPs in the 2012–2013 school year and expanded to 12 CoPs in the 2013–2014 school year with all of the original five CoPs continuing their efforts. SIIP expanded again to 14 CoPs in the 2014–2015 school year with six previously existing CoPs being dissolved due to a lack of community formation and progress. Each CoP was assigned a mentor to help them implement their proposed innovations. These mentors are called Education Innovation Fellows (EIFs).

In response to the struggles of some CoPs to form, the messaging of SIIP has evolved to invoke the simple message of "teach like we do research." This simple message carries several important messages to maintain faculty buy-in. Like research, faculty governance is respected, giving faculty jurisdiction over how their courses are designed. Like research, improving teaching is an incremental process, in which data and peer review drive decision making and knowledge generation. Like research, teaching is a career-long endeavor rather than an activity engaged in once per semester. Like research, teaching innovation must be recognized and supported by administration. Like research, faculty get to choose with whom they collaborate, creating collegial partnerships rather than receiving mandated course assignments. These principles are enacted through simple principles such as convening regular meetings (e.g., weekly) to discuss course development even among non-instructing faculty.

Through SIIP, a number of RBIS have been adopted in core engineering courses. These RBIS include project-based learning, problem-based learning, flipped courses, peer instruction, and context-rich collaborative problem solving. This last RBIS has been adopted by many CoPs with a high degree of fidelity, meaning that there was a consistent implementation of the key research-supported aspects of the instructional strategy.

3. Common elements of context-rich collaborative problem solving implemented through SIIP

While there are many different implementations of collaborative problem solving[10], the format spread through SIIP focused on small-group collaborative exercises within discussion and lab sections. In this format, students are organized into teams of three to five, either randomly assigned each period or once at the start of semester, and they then collaboratively attempt to solve a prepared worksheet or guided problem-solving activity. The worksheets or activities concentrate on "real-world" applications of the material currently being studied in the course, and are aimed at providing students with both skill practice and a broader context for understanding the content.

Each student must individually complete the worksheet or activity and submit a personal solution, but only one randomly-chosen-student's work from each team will be graded by the TA, and all group members receive this grade. This provides an incentive for team members to collaborate and to ensure that everyone in the group understands and is completing the activity.

While students are working in their teams, graduate teaching assistants and (in some classes) undergraduate course assistants circulate in the room to provide subject help and group facilitation. These graduate and undergraduate course staff meet weekly with the course instructors to receive training in group facilitation and subject-specific pedagogical techniques.

For nearly all courses that have implemented the RBIS, no changes to course scheduling were required, as collaborative problem solving was adopted within pre-existing discussion or lab sections, replacing either individual work or TA-led recitations. In some cases, such as the three TAM (Theoretical and Applied Mechanics) courses discussed in Section 5, increased staffing by TAs was needed to accommodate the new instructional style.

4. Student perceptions survey

A survey addressing student perceptions of the collaborative learning discussion format was administered in TAM *Dynamics* in the first semester of adoption of the new format (Spring 2013, $N = 416$ responses), with results as shown in Figure 1. The survey results show that the implementation through SIIP of context-rich collaborative problem solving is a high-fidelity implementation, with high student satisfaction. In particular, the length and difficulty of the activity was perceived as about right by students, and they felt that the grading scheme was very fair (65% fair versus 9% unfair). In terms of content, students considered the material to be very relevant to the course (71% relevant versus 8% not relevant) and interesting (70% interesting versus 7% not interesting). The collaborative format of the activity was thought to be very well-supported by the TAs (91% helpful versus 4% not helpful) and students much preferred to do the worksheets in a collaborative group (74% preferred group versus 11% preferred individual). In conclusion, students considered the context-rich collaborative problem solving discussion sections to be useful (74% useful versus 9% not useful).

Similar surveys have been administered in all three TAM courses (*Statics*, *Dynamics*, *Solids*) in each semester subsequent to the adoption of the collaborative learning format, with results very similar to those shown in Figure 1.

5. Mapping the spread of collaborative learning

Two of the authors acted as participant observers, both observing the adoption of the RBIS, but also acting as full participants in its adoption. Using a narrative inquiry approach, we recreate below the spread of context-rich collaborative problem solving within engineering courses at the University of Illinois. Pseudonyms are used in place of real names in the narrative. The trajectory of its spread is illustrated in Figure 2. This narrative has been member checked with other adopters of the RBIS. We then interpret this narrative through two theoretical lenses to provide some insights into why this bright spot may have formed (see Sections 6 and 7).

Prior to the formation of SIIP, context-rich collaborative problem solving had been used in various courses around campus, including the engineering sections of Calculus 2 (*Calc 2 Eng*). The use of

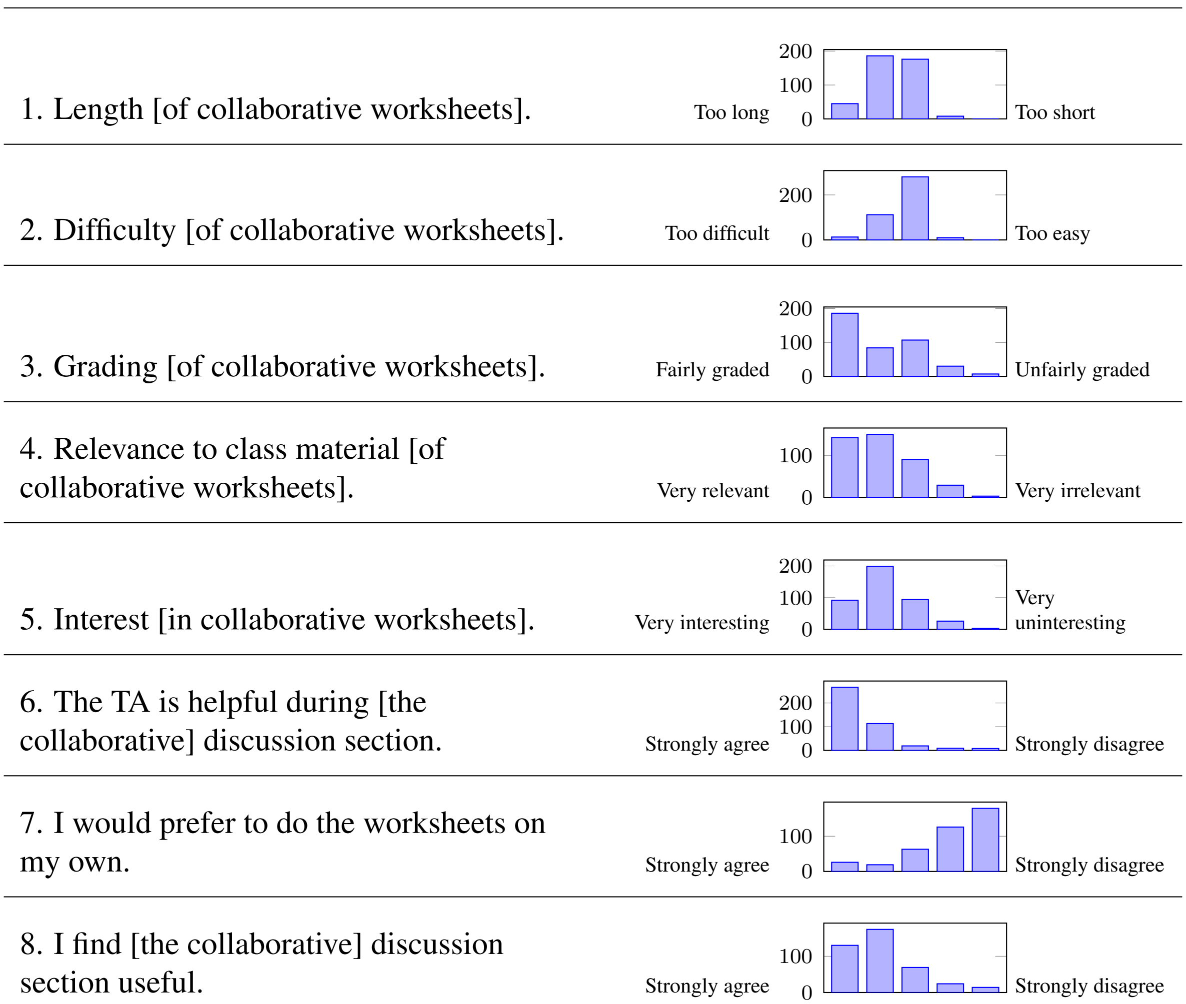

Figure 1: Student survey results from TAM *Dynamics* in Spring 2013 with $N = 416$ responses. All questions used 5-level Likert-type scales and the vertical axes show number of students giving each response. See Section 4 for discussion.

the RBIS had been implemented for years prior to SIIP and had been maintained through a system of co-teaching, in which two math professors and one engineering professor jointly presided over course instruction. During the Fall 2012 semester, the engineering co-teacher was Prof. EAST, one of the co-authors and a member of the Theoretical and Applied Mechanics (TAM) CoP.

Through Fall 2012, TAM *Dynamics* was taught with traditional lectures three times per week by a professor and a discussion section once per week in which a teaching assistant solved example problems on the board. In the Spring 2013 semester, Prof. EAST returned to Engineering and co-taught *Dynamics* with another engineering professor. Both *Dynamics* instructors were participating in the TAM CoP and collaboratively translated the context-rich problem solving methods of *Calc 2 Eng* into *Dynamics*[16]. During the implementation of the RBIS, non-instructing members of the CoP remained engaged in the development of the pedagogy by advising and discussing during weekly CoP meetings. In all subsequent semesters, other members of the TAM CoP have rotated into the instructor roles. In total, three professors and one lecturer have taught *Dynamics* using context-rich collaborative problem solving methods from Spring 2013 to Spring 2015.

In addition to *Dynamics*, the TAM CoP was also responsible for reforming two additional core engineering courses: *Statics* and *Solids*. In Spring 2014, Dr. RIVERA implemented the RBIS in *Solids* with regular feedback from Prof. EAST during TAM CoP meetings. Since Spring 2014, the RBIS has been used by two professors and two lecturers teaching *Solids*. In Fall 2015, the RBIS was implemented in *Statics* by Dr. RIVERA and Prof. JONES. The use of context-rich collaborative problem solving is continuing in Spring 2015 with instructors from the TAM CoP.

Serving as an EIF mentor for SIIP during the 2012-2013 school year and as a member of the Electrical and Computer Engineering (ECE) CoP, Prof. WANG observed the TAM CoP and their implementation of the RBIS. Based on the positive response of students to the teamwork aspects of the RBIS, he persuaded the ECE CoP to adopt the same policies and procedures as the TAM CoP for their *Intro to CE* course during the Fall 2013 semester. Like *Dynamics*, *Intro to CE* previously used discussion sections taught by graduate teaching assistants using traditional methods. Prof. WANG co-taught *Intro to CE* with different co-instructors over each of the Fall 2013 and Spring 2014 semesters. Even though the ECE CoP was dissolved after the Spring 2014 semester, the RBIS continues to be used by Prof. WANG's co-teachers who have subsequently introduced the method to their co-teachers. In total, three ECE professors and two lecturers have used context-rich collaborative problem solving.

Starting in Fall 2013, Prof. EAST became an EIF mentor to the CS CoP, attending their weekly meetings. In this context, the collaborative learning system was discussed, and subsequently adopted by CS instructors in four courses. By Spring 2014, collaborative learning had been adopted into *CS 1 non-major*, *Data Struct*, *Comp Arch*, and *CS Disc Math*. The use of the RBIS has continued in all four courses in subsequent semesters, and has now been used by two professors and four lecturers.

The final pathway by which collaborative learning was spread involved the MatSE CoP. During Fall 2013, the instructor of *MatSE Mech*, Prof. HOUSTON, heard about the successes of the RBIS and observed the TAM CoP for a semester by attending weekly CoP meetings. Having seen the use of collaborative learning within TAM courses, he adopted it in *MatSE Mech* during the

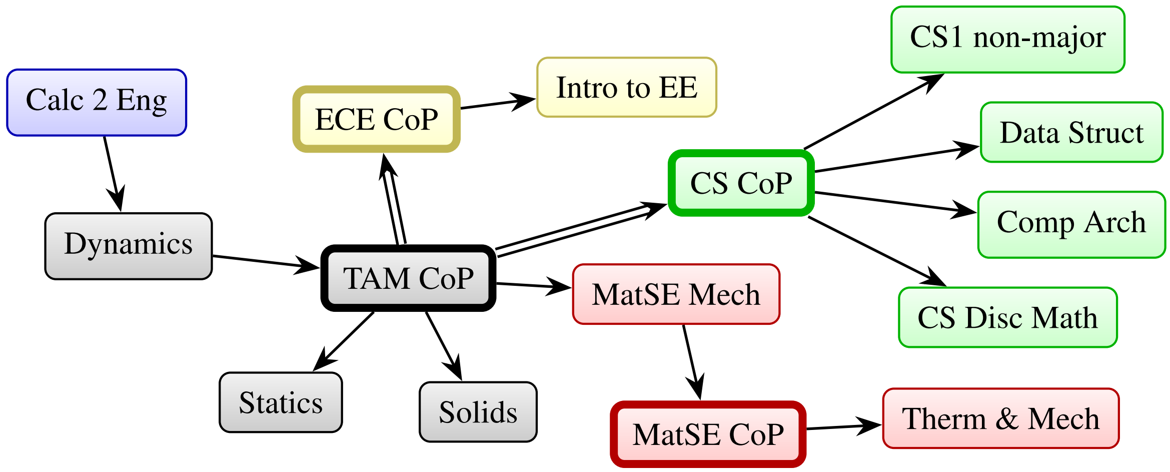

Figure 2: Spread of the collaborative learning system from the *Calc 2 Eng* course in Fall 2012 to reach a total of 10 additional courses by Fall 2014. Thin borders denote individual courses, while thick borders indicate Communities of Practice (CoP), and color denotes the university department. The arrows between boxes show the direction of spread, where single lines indicate an embedded or co-teaching arrangement (at least one semester duration), and double lines indicate an embedded Education Innovation Fellow (EIF) supported by the College of Engineering (at least one semester duration). See Section 5 for discussion.

Spring 2014. A MatSE CoP was formed during the Spring 2014 semester and other faculty members of the CoP observed the use of the RBIS. The RBIS has since been adopted into *Therm & Mech*. In total, two MatSE professors have used collaborative problem solving.

When first implementing context-rich collaborative problem solving in their courses, the MatSE CoP added the use of the research-based tool CATME for team formation and peer evaluation. The tool forms teams based on research-based methods for improving team functioning and creating more inclusive environments for underrepresented populations of students. The use of the CATME tool is now being adopted by the TAM CoP in their courses in Spring 2015.

6. A diffusion of innovations perspective on collaborative learning spread

The diffusion of innovations literature [13] shows that diffusion is enhanced by key characteristics of: (1) the innovation, (2) individual adopters, and (3) the organization.

The six key characteristics [7] of the innovation itself are relative advantage, compatibility, complexity, trialability, observability, and reinvention. The collaborative learning system fits well with this model, as it has five out of the six characteristics: it brings immediate relative advantage (increased student satisfaction and attendance in discussion sections), is very compatible with the existing course organizations structures (same schedule, same staffing, same rooms), is relatively low complexity, has immediately observable impact, and is easy to reinvent (many adopters have customized the system to their particular environment). The one characteristic that collaborative learning is lacking is trialability, because running a trial would involve separating out a group of students at some stage, which is too much effort for any adopter to have done (we are unaware of anyone having done this).

While classifications of individual adopters have been proposed in the literature, there is little agreement or empirical support for these categories [7]. We do not attempt to analyze features of individual adopters in this paper.

Seven characteristics of the organizational or system context can be identified [7;13] that assist diffusion: network structure, homophily, opinion leaders, harnessing of the opinion leaders' influence, champions, boundary spanners, and formal dissemination programs. In the case of collaborative learning, six of these seven characteristics were present. The network structure was essential and greatly enhanced by departmental communities of practice (see Section 7). The early adopters of collaborative learning were highly homophilous, having very similar professional, technical, and cultural backgrounds. Opinion leaders were explicitly enabled by the Education Innovation Fellows program within the College of Engineering and were important links both between and within departments, while champions within departments provided important early support. Boundary spanners were especially important in spreading collaborative learning between departments, which are the units of organization for teaching, and were enabled by organization programs, including the Math/Engineering Calculus co-teaching project, the Education Innovation Fellows program, and the college-supported Communities of Practice. The one characteristic that was not present for collaborative learning was formal dissemination programs.

A key aspect of the spread of collaborative learning was the fact that almost every link in Figure 2 had a long-term faculty-member involvement on both ends of the link (at least one semester). That is, it was not the case that a faculty member heard about the innovation at a workshop or other one-time event, but rather that they participated in an extended conversation that allowed familiarity to build over at least one semester. Explicit programs of the College of Engineering were instrumental in producing these long-lasting links, with the co-taught Math/Engineering calculus section providing the initial link, the college-support Communities of Practice acting as hubs (see Section 7), and the Education Innovation Fellows mentor program connecting CoPs.

7. Communities of Practice (CoP) as key elements for spreading collaborative learning

Lave and Wenger [11] developed the theory of Communities of Practice to explain and understand learning in informal settings (i.e., outside the classroom). Because our faculty seldom learn about RBIS through formal instruction, a situated approach to learning is an appropriate lens for examining how faculty learn about RBIS and how to implement them. The creation of CoPs has been shown to effectively spread tacit knowledge [4;9], decreasing the learning curve for novices, reducing creation of redundant resources or reenactments of failures, and promoting creativity [12].

Within CoPs, learning happens through the *legitimate peripheral participation* of members working collaboratively to develop knowledge and execute the practices of the community [14;15]. Legitimate participation conveys that a member's actions are acknowledged or accepted by the community. Legitimate participation in this practice can range from participation in meetings of the CoP to the delivery of the RBIS to the design of classroom policies and procedures. Peripheral participation indicates that members begin on the periphery within a community and can move toward or away from the core of the community over time. Faculty who attend weekly meetings are engaged in peripheral activities while those who are designing worksheets or delivering courses would be seen as core members of the community.

Communities are organized around a broad *domain* of interest. The faculty CoPs in our bright spot are organized by SIIP around the domain of improving student experiences and outcomes in core engineering courses. The *practice* of the community is the set of specific actions that the community engages in to explore the domain. In our context, the CoPs' practice is the use of context-rich collaborative problem solving.

Interpreting the spread of the RBIS from the perspective of CoPs reveals a CoP of CoPs. SIIP provides an overarching community in which faculty learning takes place. Faculty within SIIP are united by the common identity of innovators and course reformers of core engineering courses. Smaller embedded communities share a narrower identity and practice focused on specific courses within specific departments. Faculty in these smaller, departmental CoPs share common identities by belonging to the same department and sharing instructional responsibilities for the same courses.

The spread of the RBIS can be perceived as faculty from one departmental CoP learning through peripheral participation in the practices of other departmental CoPs. The spread of the RBIS from across the college-level CoP was always precipitated by the legitimate participation of faculty from one departmental CoP in the practices of a different departmental CoP for at least a semester. TAM's adoption was precipitated by Prof. EAST's participation in Math's practices as an instructor. ECE's and MatSE's adoption was precipitated by Prof. WANG's and HOUSTON's participation in TAM's practices (i.e., attending TAM's weekly meetings). Similarly, CS's adoption was provoked by Prof. EAST's peripheral participation in CS's CoP.

The continued legitimate participation across CoPs has enabled the continued spread of knowledge and practices across the college. As one department changes core practices such as the method for constructing teams, other departments are responding to those changes and adopting these new practices. This bi-directional spread of knowledge across network links points to communal learning rather than simply the adoption of an existing innovation.

8. Conclusions

In this paper we have mapped the spread of the context-rich collaborative problem solving RBIS at the University of Illinois at Urbana-Champaign, and provided a critical examination of this spread from the perspectives of both change theory (diffusion of innovations, Section 6) and education theory (communities of practice, Section 7).

Considering both perspectives on the adoption of the RBIS, we can identify the two key characteristics that enabled the spread of collaborative learning as:

1. Innovation characteristics: the innovation brought immediate observable benefits while integrating easily into pre-existing course formats.
2. Organization and system characteristics: the organizational network was especially effective at spreading the innovation, with CoP hubs and long-term links, both of which were explicitly created and supported by programs in the College of Engineering.

Future work will need to explore the changes in faculty's belief about teaching and learning more deeply.

Acknowledgments. This work was supported by the College of Engineering and the Department of Mechanical Science and Engineering at the University of Illinois at Urbana-Champaign as part of the Strategic Instructional Initiatives Program (SIIP), as well as by the National Science Foundation (NSF) award DUE-1347722.

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