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A Blueprint for an Ecosystem for Supporting High Quality Education for Engineering

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Abstract: This paper presents the idea and a proposed implementation of a network of Gurukuls or Centers of Excellence for engineering education in India. Facilitated by Indo Universal Collaboration for Engineering Education (IUCEE) in partnership with institutions in India, the IUCEE Gurukuls for Learning and Outcomes Based Education (iGLOBE) program addresses a vital need for institutions to develop self-reliance towards achieving excellence in engineering education. The primary role of the Gurukul in an institution is to provide an ecosystem for faculty development in a manner that will directly contribute to enhance students' learning experience. The mission of the Gurukul is to guide and mentor its faculty in improving their teaching and learning methods, in implementing outcomes based education and in conducting engineering education research.

There is a large body of literature available on effective teaching and learning through engineering education conference proceedings and journals, and in wider outlets. However, one of the key observations over the last two decades is that adoption of research-based instructional techniques into engineering classrooms is extremely low. We believe that the main reason for such non-adoption is that potential adopters are unable to contextualize the pedagogical research.

The paper lays out a vision for a network of discipline-based education researchers to contextualize and coordinate efforts between the Gurukuls and participants/practitioners. The paper considers lessons learned and best practices from efforts in the United States and lays out a blueprint for catalyzing high quality instruction in engineering colleges in India.

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1. The Engineering Education Landscape in India

As of 2015, there were more than 3470 engineering colleges in India. Student intake at the undergraduate level in engineering colleges started picking up from 2006-07. From 659,717 engineering seats in 2006, it jumped to 1.22 million in 2010 and more than 1.67 million in 2015 (Nanda, 2016).

They serve an extremely important need, training a large population of college-age youth, and providing a pathway to a better socio-economic status for hundreds of thousands of families. Although these colleges are trying to service an important national and global need for well-trained engineers, according to a National Employability Report, which is based on a study of more than 1,50,000 engineering students who graduated in 2015 from over 650 colleges, 80% of the them are unemployable (Madhavan, 2016). This appears to be a direct consequence of the shortage of well-qualified instructors as well as the absence of a support system for the available faculty to benefit from latest advances in teaching and learning innovations. The concept of teaching and learning centers is virtually non-existent.

Although the Government of India is acutely aware of this problem, most of their efforts are devoted to top down approaches. The Ministry of Human Resource and Development offers a large number of engineering faculty development programs through its agencies such as the All India Council for Technical Education (AICTE) and the Indian Society for Technical Education (ISTE). The Government also provides substantial funding to the prestigious globally recognized institutions such as the Indian Institutions of Technology and the Indian Institute of Science to develop curriculum based video and web courses (National Program for Technology Enhanced Learning, NPTEL) as well as offer on-line programs directly to students in less established colleges (Quality Excellence in Engineering Education, QEEE). The World Bank has been supporting systemic transformation of India's technical education system to make it globally competitive by assisting the Government of India to launch a Technical Education Improvement Programme (TEQIP) as a long term effort of 10-12 years and entering its third phase.

A different approach is being attempted by the Indo Universal Collaboration for Engineering (IUCEE) (https://iucee.com/), launched with initial funding from successful Indian and Indian-origin entrepreneurs. IUCEE offers the support of a global network of academic and industry experts to assist faculty at individual institutions to modify their curriculum as well as their teaching and learning processes. This effort has seen modest gains in a small number of colleges which contribute financially to keep IUCEE sustained. One success story has been B.V.B College of Engineering and Technology, Hubli, which is one of the premier engineering colleges in the state of Karnataka. The college having remained as an affiliated institution to a state University for six decades, had limited aspirations, impact and brand value. The competitive environment of the new century and change in leadership enabled the institution to set higher aspirations and undergo a systemic reform process. As a first step towards reform process the college attained the autonomous status in 2007, from the University Grants Commission, the premier regulatory body of Government of India. But, transforming from an affiliated college to autonomous college has significant challenges. Being part of the affiliated system, the college had little experience in institutional development, curriculum design, pedagogical innovations and assessment frameworks. The big game changer for the transformation process undertaken by the college was their association with IUCEE. In 2008, IUCEE conducted a series of workshops in India, by experts around the world to share the best practices in institutional development, curriculum frameworks, teaching and assessment. These workshops became the main learning platforms for senior academic leaders of the college to chart out the new directions. The college undertook a comprehensive reform process based on strategic reorientation with three primary themes; building distinctive educational experience, leading through transformative leadership and governance, and playing generative role in regional development. The success of large-scale internal organizational change and greatly improved brand positioning the college moved on to become a private State University in 2015.

Providing opportunities for engineering instructors to improve their teaching and learning is more challenging because engineering colleges in India, unlike their counterparts in the United States, tend to be independent stand-alone institutions. Whereas most engineering colleges or schools in the US are part of a comprehensive university with a large number of other departments such as education or applied psychology located at the same campus, Indian engineering colleges rarely have experts in education or social sciences on their campuses. Thus, exposure to foundational theories in teaching and learning, and their potential application in the classroom, is unlikely for a large majority of engineering instructors.

However, as seen in the case of BVBCET, a significant number of these faculty are in early stages of their academic careers and have not yet established themselves in more conventional discipline-based research due various reasons including inadequate infrastructure in the country for funding such research. Hence, there is an enormous potential for many of the engineering faculty in these colleges to engage in engineering education innovation and research, if the proper ecosystem is provided.

Before we consider the specific problem and its potential solution in the context of Engineering Colleges in India, it is important to examine how pedagogical innovations do or do not get adopted from research into practice. The rapid rise of engineering education research in the US over the last two decades provides us case studies, research papers, and even some meta-analyses on this topic.

2. Non-Adoption of Pedagogical Innovations

The non-adoption of innovative pedagogical practices into classrooms, even the ones that have been shown to be effective, is not unique to Indian engineering colleges. In fact, even with the presence of teaching and learning centers, and colocation with social scientists and education psychologists, engineering schools in the United States have historically shown very slow adoption of innovative pedagogical techniques. Furthermore, even with a robust growth in the area of engineering education research, the translation of research-based and proven educational innovations is a cause of growing concern in the US. A number of books (Fry 2014; Johri and Olds 2014), research papers (Besterfield-Sacre, Cox, Borrego, Beddoes, & Zhu, 2014; Borrego, Froyd and Hall, 2010; Henderson, Finkelstein, & Beach, 2010; Matusovich, Paretti, McNair, & Hixson, 2014), and reports (Augustine, Barrett, Cassell, Grasmick, Holliday, & Jackson, 2010; Feser, Borrego, Pimmel, & Della-Piana, 2012; NRC 2012) point out the non-adoption or non-translation of research-based instructional practices, and the phenomenon is often known as the valley or chasm of death. Research on barriers to change (Besterfield-Sacre et al., 2014; Borrego et al., 2010; Henderson & Dancy, 2007; Henderson et al., 2010; Lattuca, 2011) has revealed a variety of reasons for the valley of death for educational innovations, and there has been a strong push to investigate solutions to this problem.

In general, the lack of translation of educational innovations can be attributed to various causes, broadly in the three categories: systemic, individual adopter, and innovation ecosystem, as shown in Figure 1. From the potential adopter's perspective, there might simply be a lack of interest, a skepticism of the effectiveness of an educational innovation, pressure from the reward structure to focus on research rather than teaching and learning, fear that the innovation might not be a good fit for their classroom, reservations about their ability to practice the innovation as intended, and time and effort towards implementation. On the systemic side, there is faculty reward structure that typically promotes research over teaching or rewards 'more' teaching instead of evaluating teaching quality, situational and environmental constraints to adoption either curricular or related to infrastructure, push-back from students and reluctance on administrators' part to support the innovation infrastructure or from the point of understanding student complaints while an innovation is perfected at their institution. From the innovator's side, there might be shortcomings with the innovation or the ecosystem surrounding the innovation, such as unclear directions on how to adopt, lack of evidence showing effectiveness of innovation, no information on the time, effort and the difficulties encountered while implementing the innovation, lack of (customer) support, and lastly, no support to test the effectiveness of the innovation in new contexts.

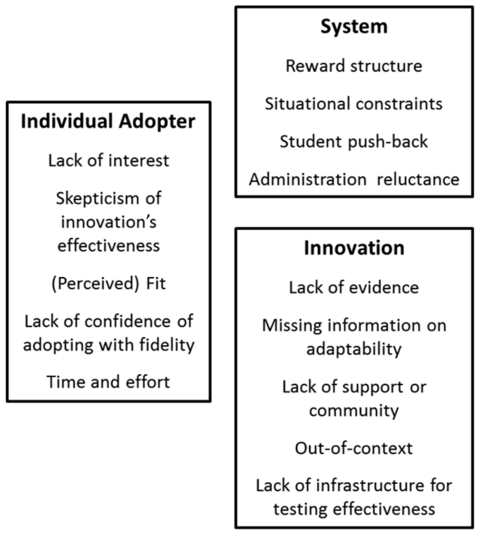

Fig. 1 Typical barriers to adoption of educational innovations

It is clear that factors from each of the three categories influence each other, and in the last few years various reports (Fairweather, 2008; Jamieson 2012;) and research studies (Henderson et al., 2010; Matusovich, Paretti, McNair, & Hixson, 2014) have called for changes at the systemic level in higher education, especially in the STEM fields. However, we believe (Sohoni & Craig, 2016) that there is an important gap in the various efforts to bring about systemic changes, and these changes should be supported by efforts that can be classified as discipline-specific or sub-discipline-specific, so that potential adopters have a support ecosystem that contextualizes educational innovations and facilitates their adoption and evaluation.

3. An Ecosystem to Support High Quality Engineering Education

Our vision for supporting high quality education is through establishing a network of well-trained faculty backed by an infrastructure with distributed and shared ownership. While the faculty champions, or discipline based education experts are central to our vision, there needs to be an infrastructure or ecosystem in place to support the faculty and to maximize the impact that they can have. The pillars of this infrastructure will be the Gurukuls.

A. Gurukuls

To address issues from all three categories (Systemic, Adopters, Innovators/Innovations), we proposed the establishment of the IUCEE Gurukuls for Learning and Outcomes Based Education (iGLOBE) program. As mentioned earlier, Indo Universal Collaboration for Engineering Education (IUCEE), established in 2007, has played a key role in enhancing the quality and global relevance of engineering education in India. The vision of IUCEE is to provide an ecosystem for this purpose with the assistance of a network of international experts from academia as well as industry. More than 200 global experts are now part of this network. Faculty and students in more than 200 engineering colleges in India are beneficiaries of this ecosystem. Important parts of this ecosystem are a variety of face-to-face workshops and on-line webinars, which cover a wide range of teaching and research topics. This ecosystem is now sustained financially though a consortium of colleges. A significant number of participants in these workshops and webinars have been able to successfully demonstrate the adoption of innovative practices in their classrooms and institutions. This has led to annual conferences as well as a journal on “Transformations in Engineering Education” which provide platforms for faculty to connect and share their experiences. The exposure to global experts has resulted in many of the faculty from India participating in international conferences such as the Annual ASEE Conference and World Engineering Education Forums (organized by International Federation of Engineering Education Societies). IUCEE has also launched an International Engineering Educator Certification Program in collaboration with IGIP (International Society for Engineering Pedagogy), Austria and supported by Microsoft. Now that individual elements of the ecosystem are showing signs of success with individual faculty, there is a need for these transformations to become institutionalized.

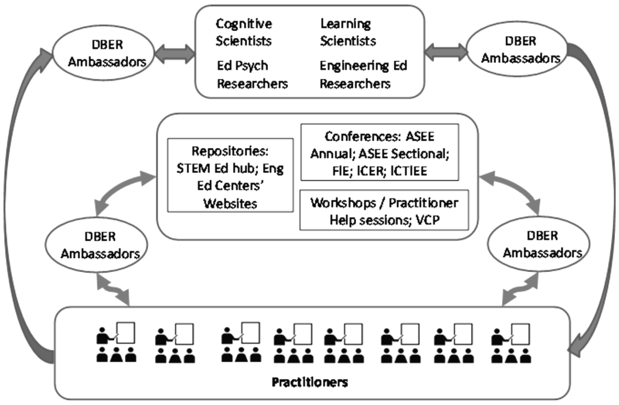

Fig. 2 The Gurukul Network facilitated by DBER Ambassadors

Recognition of the role of DBER ambassadors at the intersection of research and service, and formalizing a reward structure for the role is important to attract and retain the ambassadors. Creating the reward structure could be an extension of the current model where service roles in discipline-based divisions within ASEE or other organizations are a natural draw for DBER ambassadors. iGLOBE, or the Gurukuls will provide a natural setting for the dissemination efforts, and highlight the practical usefulness of the role played by DBER ambassadors. As DBER ambassadors work with practitioners to improve the fidelity of implementation of research based instructional innovations, and to write manuscripts on the results of testing these implementations, they would be able to demonstrate strong publications records, and involve practitioners in the publication of scholarly articles on teaching and learning. DBER ambassadors could conduct workshops at conferences focused on engineering education, but also at disciplinary conferences. They could conduct online training for practitioners, similar to ASEE's Virtual Community of Practice (American Society for Engineering Education, 2016), and even contribute book chapters for books on educational innovations written in the context of specific engineering disciplines. Over a period of time DBER experts will also emerge from the Gurukuls and further strengthen the ecosystem.

With a strong need for institutions in India to incentivize training for its relatively under-served and underprepared engineering faculty, there are a number of opportunities for DBER ambassadors to get involved and be rewarded for their involvement. Besides the possibility of collaborating on high quality research papers and guiding facilitators to test innovations in different contexts, DBER ambassadors can look forward to intrinsic rewards, especially in the context of iGLOBE. Several potential DBER ambassadors, at least initially, will be faculty already involved with IUCEE. These faculty members typically tend to be of Indian origin, usually first generation immigrants to the US or other countries. They received their college education in India, and they volunteer for IUCEE because they would like to give back to the system that enabled their own successful careers. The idea that they can directly contribute to improving the quality of engineering education in Indian institutions, and train a generation of engineering educators is likely to appeal to them. Establishing stronger ties with these institutions and their personnel through their role as DBER ambassadors is also likely to lead to other meaningful roles, such as serving on the institutions' boards.

4. Discipline-Based Engineering Education Research Translation

A. Transfer of Expertise

Most practitioners in engineering are likely well versed with the scientific method at some level. There is a strong likelihood that an understanding of concepts such as isolating variables, consistent measurement and the need to understand what is being manipulated and measured are already present. It is highly likely that most practitioners apply these concepts within their own research or teach these concepts to students. However, such expertise does not always transfer well (Ericsson & Charness, 1994). Thus, it is not always easy for this skill set to generalize when trying to understand research in other areas.

Many factors influence the transfer of basic research expertise between skill areas. Even for experts, the likelihood that transfer will occur depends on the perceived similarity between tasks (Kimball & Holyoak, 2005). If the situation or culture is not conducive for transfer, it will not occur. This point is highly related to the second point. Not all experts are equal. An expert with more experience or specific training will be more likely to transfer skills (Chi, Feltovich, & Glaser, 1981). So, the level of expertise and specific training or experience with application of research skills in Engineering Education matters. Without the additional training, practitioners and more novice domain area researchers are more likely to utilize research expertise as “routine expertise” that tends to be compartmentalized into familiar domain-specific tasks (Hatano & Inagaki, 1986). “Adaptive expertise” is needed for transfer of research skills. For adaptive expertise to develop, four supports must be in place (Hatano, 2013; Hatano & Inagaki, 1992). First, novel problems in the new area must be encountered on regular bases which allows for generalizability of skills to develop. Second, interactive dialogues must be engaged in on the topics. Third, the expert must be surrounded by a group that values this level of understanding. Finally, the expert must free of other demands that prevent them from engaging in the other three activities.

In light of these requirements, it is not surprising that instructors and engineering domain experts have difficulty interpreting research findings, implementing them in useful ways, and testing them effectively within their classrooms. Because of this difficultly in transfer, it is important that an experienced expert such as a DBER ambassador collaborate in the implementation.

Gurukuls could play a key role in facilitating the transfer of expertise. By supporting a group of likeminded individuals, they foster the development of adaptive expertise in research. These discussions on implementation of research findings and future evaluations within the Gurukuls will help the practitioner become more effective. But, it can also help the skilled DBER ambassadors by exposing them to novel problems by assisting practitioner's transfer of educational innovations into the classroom.

B. Mixed Methodology for Implementation - Validity

It is important to ensure that the chosen innovation is implemented correctly. These areas often have specific vocabulary and methodologies that can be difficult to transition and implement. Because of this, it is often necessary to reach out to other collaborators, either a colleague experienced in disciplinary-based education or an expert with the learning innovation. While this could slow down implementation, it can be essential for valid implantation and assessment within the classroom.

Mixed methodologies are often needed to understanding an instructional innovation in a new classroom context. These mixed methodologies would include not only a rigorous quantitative outcome measure, but also potentially a qualitative measure of how the innovation impacts the process of learning. An objectively validated pretest and posttest (immediate or delayed) allows the amount of learning gained to be measured. This gain allows for a quantitative measure for the impact of the innovation, answering the basic question "Did the students learn from the implementation?" However, it is often important to identify how this learning came about. This can be done by looking at the process that students underwent during the class. Many practitioners are well-versed with quantitative methods of assessment, and could be unfamiliar with qualitative methods and even less familiar with how to integrate the two (See Chi, 1997 for a detail summary of one method for this). These could include recording or systematic live coding of the implementation, reviewing written artifacts from students to find corroborating evidence of impact, or conducting a series of focus groups with students. We urge instructors to think about the methods most suited for their evaluation, and to reach out and collaborate with those who have expertise in these methods.

It is important to use a form of assessment that can measure direct classroom impact. While all classrooms already have assessments, these assessments might not be sensitive or targeted enough to detect the implementation's impact. These instructor created assessments often have not had the validation needed give ensure that 1) the assessments is testing what was created to test and 2) the items are sensitive enough to target a large enough number of concepts. When creating these tests it is important to ask questions that have objective answers to at require students to exhibit learned knowledge to answer the question. Subjective questions that ask students how much they think they have learned or that ask student to indicate the areas they feel as if they have learned are not always useful measures. This is because students are prone to overestimate the level of their knowledge (Kruger & Dunning, 1999) and falsely express their knowledge level (Commander & Stanwyck, 1997; Glenberg, Wilkinson & Epstein1982). Additionally, while it is good that the individual questions within an assessment targets specific key points, it is important to ensure that the question bank is robust enough to cover a large amount of course content at deeper conceptual levels. This often requires students to apply the knowledge in new areas and show understanding of a concept (or related concept) multiple times. This is specifically important for major concepts. The multiple instances can be used to derive a composite understanding of the underlying concept which is more stable than that based on an individual question.

To ensure that a test is robust enough to show an effect of the intervention, it is important that a rigorous process is used for assessment creation. The process should start with a cognitive task analysis which will identify the knowledge from two or more subject experts. This often involves multiple rounds of interviews with experts (See Clark, Feldon, van Merriënboer, Yates, & Early 2008 for a review of CTA procedures). Afterward, questions can be created to target the identified concepts. However, an assessment also needs to be validated. This allows for questions that are not sensitive enough to be removed (normally through an Item Analysis procedure) and for the construct validity to be established.

These procedures are often beyond the expertise and available timeframe of a typical instructor. Because of this, house measures are often created using some form of face validity (i.e., verification by an expert that the test is accurate and focused on the right level for the target audience). If this method is implemented, then it is best to get reviews from multiple independent experts. However, this is not ideal and poses questions for generalizability of results especially if significant results are not found. Two other alternatives are to use the assessments from the original research studies (or replication studies within the area) if they are close enough or to search for a validated topic area test within the broader literature to pair with in house created assessments and class grades. In all of these cases, it is good to have multiple measures of learning if possible. Similar results on multiple measures provide stronger evidence for the success or failure of the innovation's implementation.

C. Repositories of Educational Innovations

It can be difficult for practitioners to find reliable information on educational innovations with evidence within a wider domain. However, the idea of presenting research on teaching and learning in the context of particular disciplines is not new (Lohmann & Froyd, 2010; Singer, Nielsen & Schweingruber, 2012). Science education, Math education, and

Engineering Education research communities have existed for decades. The What Works Clearinghouse (U. S. Department of Education, 2016) from the Institute of Educational Sciences at the U. S. Department of Education is one example of a research evidence repository. The WCC works to identify studies with credible and reliable evidence of the effectiveness and disseminates summary information and free reports on the WWC website. The WCC currently has over 700 summaries on effective educational innovations and has 10500 reviewed studies available for search. Within the disciplinary sciences, there have been several active discipline-specific movements, such as Physics education and Biology education research communities. CLEERhub (STEMEdHub, 2016) is a repository funded by NSF which focuses on Engineering Education.

One of the more recent faculty development initiatives, organized by ASEE and sponsored by NSF, Virtual Communities of Practice (VCPs) aimed to bring together practitioners in specific disciplines with faculty active in the scholarship of teaching and learning in those disciplines. One of the authors participated in the VCP and found it to be useful, but more as an introduction to research-based instructional practices, than a comprehensive resource to walk a practitioner through implementation and evaluation of an innovation. The main issue again was the general context in which most examples of innovative teaching practices were presented. The participants saw the value of various practices such as peer instruction, but found it hard to translate it to the context of their courses, let alone set up an evaluation of its effectiveness. Much like the 'last-mile' problem faced by providers and consumers of high-speed internet, the books and research papers available on research methods, and even on effective instructional practices are inaccessible to most instructors. Switching one's primary field of research to engineering or CS education should not be a prerequisite to understanding, correctly applying, and sharing the results of applying research-based instructional strategies in the classroom.

Besides repositories of research on the scholarship of teaching and learning, there are some repositories of actual educational resources themselves. Multimedia Educational Resource for Learning and Online Teaching, MERLOT (California State University System, 2016), is a curated collection of free and open online teaching, learning, and faculty development services contributed and used by an international education community. The MERLOT project began in 1997, when the California State University Center for Distributed Learning developed and provided free access to open educational resources. These resources can range from lectures that are publicly available on websites like YouTube, to electronic books, to entire online courses. An important feature of MERLOT is that all the materials are curated and reviewed by panels of experts. Resources are categorized by discipline and sub-discipline. For example, within Science and Technology, there is a category for Computer Science, and within Computer Science, there are 17 subcategories, based on the ACM/IEEE CS2013 standard (Joint Task Force on Computing Curricula Association for Computing Machinery (ACM) IEEE Computer Society, 2016).

It is important for the translation of educational research to the classroom, that such repositories be available, be easy to navigate, and for practitioners to be exposed to them. Thus, once again, there is an important role for DBER ambassadors to further curate such resources and introduce them to practitioners in their appropriate contexts. The iGLOBE network will be ideally positioned to facilitate this, and to even host repositories that will be particularly useful for engineering educators in India.

5. Conclusions

Supporting high quality education in engineering in the Indian context requires an ecosystem which includes experts from different domains and from different institutions around the world. Transfer of the expertise and knowledge between these domains and institutions is non-trivial, and the transformation and improvement of an educational environment is not a quick process. Practitioners and domain area researchers need regular exposure applying educational research methods to novel problems, continuous interactive dialogues on the educational innovations, a peer group that values the importance of educational innovations and freedom to engage the implementation of educational innovations (Hatano, 2013; Hatano & Inagaki, 1992).

The authors believe that Gurukuls will be ideal for facilitating and speeding up this transition. The iGLOBE system will provide knowledge repositories in the form of practical implementation knowledge and human experts (e.g., DBER ambassadors and like-minded practitioners). Initially, a network of about 15 Gurukuls will be created from among the interested colleges belonging to the IUCEE Consortium. The abilities of each Gurukul will vary depending on its own culture and history of engagement in the process of teaching and learning innovations. For example, BVBCET is expected to emerge as a natural leader among the Gurukuls because of its history of implementation of innovations. A process will be established for identifying, motivating and mentoring practitioners and future DBER ambassadors within each Gurukul. These will be connected with DBER ambassadors identified within ASEE and similar organizations. IUCEE will facilitate the translation of Discipline Based Engineering Education Research between these groups via webinars and workshops as well the repositories of innovations. This process is expected to lead to an ecosystem of a growing network of effective practitioners within each Gurukul connected with DBER ambassadors from around the world. Success of the Gurukul concept publicized through various media including conferences will encourage gradual increase in the number of Gurukuls and their ability to adapt innovations to their own institutional culture, resulting in overall enhancements in the quality of engineering education.

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