Making knowledge accessible: A comparative study of engineering teaching across three countries

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***Abstract*— This is a full research paper. Intentional decision making around course design and execution by instructors is a very important aspect of teaching and learning. Understanding instructor beliefs about knowledge and their students is critical for any educational endeavor in that instructor beliefs often guide how they choose to structure their course and what they choose to evaluate. However, despite all the rhetoric on the need to improve teaching in engineering education, there are surprisingly few close-up studies on what contemporary instructors are doing in their classrooms. A further limitation is that most studies take place in one country which then comes to stand in for a sort of universal context. We seek to understand how instructors' knowledge and beliefs about disciplinary knowledge shape the design of instruction, assessment and perception of students. This work studies how engineering instructors in three different countries use their knowledge of disciplinary concepts and beliefs about teaching and learning, i.e. pedagogical content knowledge, to design their courses and teach content. We are interested in understanding how the different national and institutional contexts make possible potential differences in approaches to teaching.**

Keywords*— *teaching strategies, approaches to learning, comparative study, pedagogical content knowledge

I. Introduction

Much research on engineering teaching and learning is focused on how students' engagement with knowledge is fostered by teaching practices [1]; several researchers have posited that active learning activities provide opportunities for students to learn more and thus recommend that instructors are intentional in their design of active learning experiences [2]–[4]. As such, moving away from lecturing, the traditional mode of engineering classes, has been called for repeatedly. Another body of research tends to focus on how we learn. Here, there is much support for a constructivist theory which recognizes the importance of learners actively making sense of knowledge. Such research studies have sought to highlight the interconnectedness of concepts and the importance of linking new content to prior knowledge and experience [5]. Consequently, the intentional decision making around course design and execution by instructors is a very important aspect of teaching and learning.

However, there is a dimension of teaching and learning that is not often included in the mainstream discourse - how instructors' personal beliefs about knowledge and their students influence how they design and implement activities in their classes. This is a crucial area for research in that it can explain why instructors do not necessarily adopt the practices that the educational research community views as impactful on student learning. Understanding instructor beliefs about knowledge and their students is critical for any educational endeavor in that instructor beliefs often guide how they choose to structure their course and what they choose to evaluate. However, instructors' intentions as they relate to course design and conceptions of knowledge cannot be considered outside of the context of disciplinary knowledge. Disciplinary knowledge has been known to have significant impact on the design and development of curriculum and even more notably classroom activities, assessment and overall expected outcomes. In educational research, this blend of knowledge and beliefs about content as well as an understanding of which practices are best used to teach this content is defined as pedagogical content knowledge. In this study, we seek to understand how instructors' pedagogical content knowledge shapes the design of instruction, assessment and perception of students' understanding. A topic that has been identified as not sufficiently researched in engineering education [6]. This study aims to answer the following question:

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"What influence, if any, does engineering instructors' pedagogical content knowledge have on how they design and teach classes?"

This work is framed and guided by the pedagogical content knowledge (PCK) framework. PCK highlights how knowledge and beliefs held by instructors influence their classroom practice. These beliefs often guide how instruction is sequenced, the amount of emphasis placed on particular content based on instructors' perception of level of difficulty for students, knowledge of content-specific strategies that can build students' conceptual understanding, as well as how to design and execute assessments. In an engineering context specifically, PCK has been used to compare instructors believes with their students and reveal students' patterns of thinking that instructors weren't aware of [7].

II. THEORATICAL FRAMEWORK

The pedagogical content knowledge (PCK) framework is used in research to highlight how knowledge and beliefs held by instructors influence their classroom practice. The premise of this framework is that as instructors blend their own knowledge about specific content and their experiences they tend to present content to their students in the form they believe best enables learning [8]–[10]. In addition, instructors use their PCK to determine what concepts are important for emphasis, teaching strategies that are most effective for teaching specific topics and activities necessary to foster conceptual understanding [11]. Though PCK has its roots in science education and is often used as a construct for measuring science instructors' use of their own knowledge to becoming effective in teaching, PCK can also be used as a guiding principle for data collection and analysis in studies aimed at investigating how instructors choose to design their courses to have the most impact on student learning. The five components of PCK as discussed by [8] are:

1. Orientations toward teaching: involves daily instructional decisions regarding class objectives and content, student engagement and use of curricular materials (p. 97).

2. Knowledge and beliefs about curriculum: involve how information about the goals of the class is communicated to the students over the duration of the course as well as the activities and materials used in achieving these goals as well as how the current course fits into the broader context of the curriculum (p. 104).

3. Knowledge and beliefs about students' understanding of specific topics: involves prerequisite knowledge and skills students are required to have, how teachers incorporate individual student ability in the dissemination of class activities and what concepts students find difficult to understand (p. 105).

4. Knowledge and beliefs about assessment: this involves decisions made about appropriate means of assessing student learning such as approaches, activities or specific procedures (p.109).

5. Knowledge and beliefs about instructional strategies for teaching: this involves various approaches used to represent scientific concepts and principles in a manner that best facilitates student learning (p. 109).

III. METHODS

A. Study overview

This study is drawn from a large research collaboration between institutions in England, South Africa (SA) and the United States (US). In each country, two chemical engineering programs at two dissimilar institutions were identified and invited to participate. The larger study in which this paper sits is centered on the longitudinal and comparative investigation of how curriculum influences student learning outcome in both chemistry and chemical engineering, i.e. across the twelve programs of study. Data collection involves student interviews from their first year to final year and first year of work, classroom recordings followed by instructor interviews and the collection and analysis of course and curriculum documents. For this paper, we focus only on the first-year classroom recordings and instructor interviews in Chemical engineering. The class chosen to be recorded represented a core module of each program. The purpose of the recording was to document the content being covered in the class, what concepts the instructors emphasized as important as well as to explore the pedagogical choices made in the design of the class session. Class sessions - and consequently the recordings - were between fifty and seventy-five minutes long, with one class session recorded for each instructor from each institution, making up a total of six recordings in one given year. Consent forms were distributed to instructors both for the recordings and the interviews and all IRB practices for recording a class were followed at the respective institutions.

B. Participants and interview protocol

Four of the instructors had PhDs and teaching experience ranged from 3 to 32 years, with all six instructors' experience being in the range of 3 to 10 years. The six instructors were each interviewed following the classroom recordings and were asked to provide more information about the choices made in their course design and content delivery. The interviews sought to uncover what knowledge instructors believe is essential at this point in their respective programs and the discipline by extension. We prepared a semi-structured interview protocol composed of a combination of questions focusing on the dimensions of PCK and the session-specific inquiries. The protocol was divided into sections addressing the students in the course, the specified class session that was recorded, how the session fits into the rest of the course, how the instructor relates to the content of their class, and general information about teaching style and influences. The research team watched the recording and modified the existing instructor protocol to probe interesting instances observed from the video. Each interview was conducted by a member of the research team and lasted approximately one hour. Examples of questions asked are listed below:

- Choice of overall teaching methods
    - During the video that we recorded, we noted that you have chosen to use different

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  - technologies/tools – blackboard, projector, and book extensively. Could you talk more about that choice?
- Use of different forms of representations
  - You extensively used graphs for explaining concepts in the class. What is the importance of using graphs in teaching/learning of chemical engineering?
- Importance of numerical problem solving
  - You introduce a concept, provide an example and then get students to work through example questions, as a process why does this work for the students?
  - Why do you emphasize the practice questions on [the Learning Management System]? And how does this relate to what students are doing in the lecture?
  - Your class made extensive use of calculation problems to discuss the content. Could you talk about the reasoning for that?
- Connection to industry
  - What is the relationship between the lecture and what students may do in industry in the future?
- Assessment
  - What is the relationship between the practicals, assessment and the lecture?
  - Can you tell me about the role of assessment in learning engineering?

C. *Features of the six courses*

The project aimed to focus on a class in a representative core course in that year of that program. In this paper we focus on the six chemical engineering programs, and because only one of them has a chemical engineering course in the first year, for the other five where students are in a general engineering program we focused on a chemistry course that was mandatory for first year students intending to declare chemical engineering as their major course of study. Being first year courses that all students had to complete, the sections observed were large, ranging from 120 to 350 maximum seats. Instructors were not expected to provide any kind of demographic information or breakdown for their classes.

D. *Analysis*

The transcribed interviews were analyzed using the five dimensions of PCK, defined above. It is important to note that the PCK framework was not used at the initial design of the study, yet we found several instances where the instructors' discussion of their approaches to teaching aligned with tenets of the framework. We discuss these in details in the next section.

IV. Preliminary Findings

A. *Orientation towards teaching*

Three of the instructors (both South Africans and one US) put forward an explicit view that the purpose of their teaching was to get students to not just manipulate calculations (which they felt had been the focus at high school) but to rather understand the concepts, to know what the numbers mean. These instructors aimed their teaching towards trying to shift students towards what could be termed a deep approach to learning. Some of these instructors also offered a reason for the stress on understanding, for example, one noted that students dislike his stress on conceptual understanding as they want to just get the calculations right so they can pass the course, but he emphasizes that as engineers they will need to understand the concepts in order to decide which calculations might be needed to solve a particular problem. We can see one of the instructor's thinking process behind this in the following quote:

> *"so in all of my classes I try and cover about the conceptual and the calculation, so these engineering students must be able to do calculations but they usually find the calculations easy because they are good at Math, but they find the conceptual work more difficult, why they get to the calculations, what does calculations mean, how we tie that into our theory of Chemistry and our theory of how chemical species interact and so forth, so in all of my lectures I try and have this tied together …"- SA faculty 1*

The two English instructors tended to stress the skills that were an outcome of the course and linked these also to their ultimate career destination. The one English instructor focused on encouraging students towards "higher order skills" more akin to discovery-based learning. The other English instructor also stressed that students needed to get in the habit of doing things independently.

The final (US) instructor did not offer explicit statements around the purpose of her teaching although she did feel that students did not work hard enough as they managed to achieve A's in high school with minimal effort. She also worried about students juggling other classes, but she did not say much about the purposes of this course and what kind of outcomes she prioritized.

B. *Knowledge and beliefs about the curriculum*

None of the instructors explicitly mentioned how they were connecting what was taught in the specific recorded lecture to the overall objectives of the program, or how this course linked to other courses. An instant that came close to that as seen from the following quote is the instructor commenting on skills needed for the profession in general:

> *"we want to get them or at least start them to think like engineers…we want them to have teamwork skills and we get*

that in a project and we also talk about teamwork and how to work on a team and those things. We want them to develop some initial professional practice skills. They should be able to present and we make them all do presentations. They should be able to, at least do rudimentary technical writing and those kinds of things."-US faculty 2

When asked after the class why they chose to do what they did, the majority of the instructors commented on how they intentionally planned the activities and materials to achieve the class goals but none were seen to explicitly link this to the broader curriculum, or indeed to communicate this to the students. This might have been due at least in part to the research design in this study which did not explicitly ask instructors to talk about this, but at the same time it does offer some evidence that this is not a significant priority for these instructors.

C. Knowledge and beliefs about studentds' understanding of specific topics

Some instructors talked explicitly about staging the progression of concepts, and about what prerequisite knowledge might be for this course. Because this is a first-year course, many of the instructors based what they think about the students' prerequisite knowledge on their readiness for college overall, one US lecturer mentioned limited knowledge of calculus at this point, one English instructor mentioned that students coming in with different chemistry backgrounds. We see the instructors mentioning how the students coming in are at different levels and they do not all necessarily know the basics.

"there are people there that don't know chemistry a lot or they had only chemistry at the GCSEs level. So, they need, you know, as basic as what is one mole of the substance and things like that. So, sometimes, that is a bit challenging to find the level that will satisfy all students"-English faculty 1

D. Knowledge and beliefs about assessment

It was interesting to note that in response to very similar interview prompts, it was only the two US instructors who spoke much about the assessment structures in their courses. These two instructors generally talked about their formal assessment tools like tests and quizzes. They mentioned the number of tests they give to the students throughout the semester and how they distribute the course material over the different tests. They also talked about other assessment tools that they use to gauge the students learning and make sure they are engaged in the class, like giving them problems to work out in a group during the class or a recitation session, asking them questions as they explain the material, or even using interactive technologies like clickers as was mentioned by one professor.

"So tests are really for us. We have to assess whether the students know the material or not. We could do this course without the quizzes or the homework, and life would be a lot easier for me. I wouldn't be writing a weekly quiz and doing all this homework. That's really for them to assess, do I know this material?" -US faculty 1

E. Knowledge and beliefs about instructional strategies for teaching

Instructors mentioned many different instructional strategies and why they chose to do what they did. The two main themes that the instructors focused on when asked about their teaching strategies were keeping the students engaged and connecting theory to application to build understanding. An example on the latter can be seen here:

"It's not just about the skill of being able to use the software, and press the buttons, and get an answer. It's about what makes them think, and makes them more inquisitive about what's going on, and about how that then develops later through the course into year two"-English faculty 2

Across the three sites, the instructors provided the students with work out problems to solve on their own or in groups, and not just watch the instructor solving it or 'reading' the solution later on. That strategy was discussed as to ensure the students were learning and remained engaged in the class. One instructor mentioned another strategy of peer learning, and another instructor mentioned the details of how they manage the class from restricting use of technology in lecture and creating live demonstrations whenever possible.

V. Discussion

Our findings indicate that all six instructors gave very explicit evidence on how they make choices about what they do in their classes. This intentionality is noteworthy, particularly in general first-year courses that run the risk of becoming routine or almost mechanical. Overall, we found these instructors to be thoughtful and intentional in their ability to give clear accounts of what they focus on in their teaching. Each instructors' interview demonstrated dimensions of the PCK framework, and it is clear it is related not only to their dispositions but also the context in which they teach. We did note a particular emphasis on three dimensions: orientation towards teaching, knowledge and beliefs about students' understanding of specific topics, and knowledge and beliefs about instructional strategies. Overall findings across these domains are summarized here.

Some instructors were particularly focused on the knowledge in their course, its relevance, how they stage progression, how they emphasize understanding and not just calculations. Most instructors were focused towards the broader purposes of why these students needed to learn the material in this course for their future careers, although they did not necessarily link it to other courses in the program. Perhaps for first-year students - those for whom career planning and aspirations are still a long way off - it would be valuable to put additional class time and resources into clearly establishing ties between the material and the rest of their undergraduate curriculum given how much closer it would feel to the students. This should not replace connections to eventual careers, rather it should complement them.

All the instructors were able to talk explicitly about the instructional strategies they used and why they used them. The two US instructors had a lot more terminology at hand for describing the kind of active learning pedagogies that they used.

We were interested to note that instructors did not speak much about assessment or the broader curriculum (relation to other courses). This might be an artifact of the interview protocol we used, but we also think this might illustrate aspects of higher education teaching. The PCK framework was developed in the K-12 context where teachers are more subject to assessment and curricular structures that are not of their choosing. They are also explicitly trained to execute these structures. In higher education, instructors have more autonomy in their courses and thus less need to reference other courses - the assumption is that students will do this linking. This in turn raises questions surrounding how educators are prepared for this autonomy and subsequently how capable students are of drawing these connections between their courses on their own.

VI. Conclusion and Future Work

Overall, we saw evidence of instructors using their knowledge of the content and instructional strategies to create the types of learning experiences their students can benefit from. Primarily, the importance of the course and how the knowledge being presented to students forms the foundation for the rest of their degrees was described as the main determinant of how courses were designed. We have demonstrated that some instructors choose to use activities that actively engage students in the classroom as this is how instructors believe learning is best achieved. Additionally, some instructors also discuss the importance of creating and using scenarios that challenge students to go beyond the surface of the information presented in class.

Currently, we are analyzing the instructor interviews for all project years across all institutional and national contexts (n = 24 including the six presented in this work). We hope that by applying the tenets of the PCK framework to these data we will be able to uncover if and how changes in subject matter difficulty impact how instructors design their courses so as to build a comparative analysis of instructor intentionality and strategy. Additionally, it will be worthwhile to further explore the discrepancy in instructors' access to and use of pedagogy-related terminology across national contexts that emerged during the analysis of the first-year data.

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