

Article

Using Legitimation Code Theory to Conceptualize Learning Opportunities in Fluid Mechanics

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Abstract: With widespread industry feedback on engineering graduates' lack of technical skills and research demonstrating that higher education does not effectively facilitate the development of open-ended problem-solving competencies, many educators are attempting to implement measures that address these concerns. In order to properly formulate sensible interventions that result in meaningful improvements in student outcomes, useful educational measurement and analysis approaches are needed. Legitimation Code Theory (LCT) has rapidly emerged as an effective, theoretically informed 'toolkit' offering a suite of dimensions through which to observe, analyze, interpret, and design teaching and learning practices. LCT Semantics has been used to help engineering educators unpack both levels of engineering knowledge abstraction and the complexity of engineering terms, while LCT Specialization focuses on knowledge practices (using the epistemic plane) and enables a visualization and differentiation between kinds of phenomena and the fixed versus open-ended methods with which to approach a particular phenomenon. Drawing on a range of initiatives to enable an improved practical grasp of fluid mechanics concepts, this paper presents a description and graphic LCT analysis of student learning that has been designed to anchor the 'purist' principles underpinning applied fluid mechanics concepts (such as in piping and pump network design) by way of concerted 'doctrinal' practices, and the exposure to more open-ended practical situations involving peer learning/group work, allowing educators to visualize the code clash between the curriculum and the world of work.

Keywords: fluid mechanics; Legitimation Code Theory; undergraduate teaching

1. Introduction

Science and engineering education battles with a number of disjunctures in purpose, epistemology, and implementation. Many courses (for instance, fluid mechanics) have a significant focus on theoretical 'content'—teaching the material with an approach often called scientific realism [1]. Others present and examine material in a way that is more applied (either practically or in calculation exercises linked to examples), but which can descend into 'cookbook exercises' of dubious educational benefit [2]. The approaches used are for the most part manifestations of educators attempting to 'face both ways' [3]: toward both the theoretical knowledge base and increasingly complex application contexts, requiring working practical or pragmatic knowledge. Thus, one sees more theory and more practice being introduced into an already full curriculum and occasionally a shift in one direction or the other, which is sometimes to the detriment of the students' epistemic access [4] or value in the workplace. Courses can no longer focus only on tools (for instance, manipulating the mathematics of Navier–Stokes equations or calculating pump efficiency); they also need to focus on problems (system design, application to poverty alleviation or unemployment, development of new technologies or application of old to new systems, and so forth) in socioeconomic contexts, as indicated by the holistic International Engineering

Alliance competency profiles [5]. Then, the tools would be used only to the limit of their relevance for analyzing such problems, and not for their own sake: tools are only as useful as the problems they can solve.

As these debates illustrate, knowledge-building practices are neither homogeneous nor royal roads to cumulative knowledge building [6]: stronger epistemic relations (i.e., a strong focus on disciplinary science knowledge) do not by themselves guarantee intellectual progress. Cumulative knowledge building requires both a diversity of ideas and a shared means of navigating among these—in other words, multiple repertoires and an expanding collective reservoir [7]. To have these tools to hand, as a rephrasing of ‘practical reasoning’ [8], is to have access to the tool that solves the problem, while also having a deep and conscious understanding of the scientific and epistemic underpinnings: the ‘know why’ that is essential for 21st century complexity [9].

The educational literature, and in-practice educators themselves, have examined and trialed a number of methodologies and approaches that may address (part(s) of) this concern, including approaches such as problem-based learning e.g., [10], project-based learning e.g., [11], or flipped classrooms e.g., [12]. Many of these show real improvements in student knowledge and skill development. However, one shortcoming in many of these studies is the chronocentricity inherent in their set-up and evaluation. The efficacy of the program is commonly assessed within the same subject/module period. Progressivist pedagogical initiatives may appear successful within the timeframe of the actual course, but perhaps the true measure of transformative epistemic access is its continued usefulness to students and the manifestation of successful epistemic access and integration. Very often this is only evident after graduation, or in later academic years. Few academics have the benefit of a (un)planned longitudinal view, but where it is found, this view can be insightful. A second shortcoming is that active learning approaches—while intuitively appropriate in professional education designed to bridge the theory–practice divide—have not necessarily been adequately problematized from the perspective of forms of knowledge and associated practices. That is to say, our tools for analyzing how and why these interventions work is often limited to a ‘show and tell’—analytical tools would enhance this discussion.

The discussion below firstly draws on collaborative work across the authors’ department, its undergraduate program, academic staff access to initiatives, and their effects by way of observation, practice-sharing, and discussion, to give insight into gaps that persist in undergraduate skills and knowledge, even post ‘educational initiatives’, in a longer term view. Further, and most principally, the emerging field of Legitimation Code Theory (LCT) facilitates understanding of the nature and implications of these initiatives. LCT gives insight into what the connection between theory and practice is, as experienced by students and manifested throughout their undergraduate careers. LCT provides the tools for the investigation, analysis, and interpretation of ‘knowledge practices’ [13].

This paper aims to accomplish two objectives: it firstly draws on the experience and observation of interventions carried out in a second-year fluid mechanics module, as it plays out specifically in the final Capstone research project, to draw insight into fluid mechanics teaching more generally. Secondly, and potentially more usefully, the paper conceptualizes an extended approach to using LCT dimensions to visualize teaching strategies intended to facilitate improved learning outcomes, illustrated using examples from fluid mechanics, with the intent of giving educators an additional tool for analyzing their practices and curricula, and potentially bridging gaps between the curriculum and the world of work.

2. Theoretical Framework in Context

Legitimation Code Theory has emerged in the sociology of education as a powerful and illustrative ‘toolkit’ to analyze the organising principles of knowledge practices, their associated meaning-making systems, and the nature of knower dispositions [13]. For readers new to LCT, there are several excellent and accessible texts introducing these ideas, such as for instance [13–15]. The key to LCT is the idea of making visible *what* or *who* legitimates practices, and *how* they do so, so as to enable epistemic and

social access to knowledge practices. Educators who understand the forms of and relationship between knowledge, knowing, and knowers are better equipped to address teaching, learning, and assessment challenges, particularly in increasingly diverse and complex 21st century educational contexts. In this paper, we suggest that LCT offers a practical set of tools through which engineering educators can interrogate forms of knowledge and knowing.

Over the past decade, as challenges in the recruitment, retention, and successful graduation of Science, Technology, Engineering and Mathematics (STEM) students became a global concern, education researchers began to use the LCT dimensions of Semantics and Specialization to interrogate existing practices. Hence, we find researchers looking at the gaps between school and the first-year biology curriculum [16], unpacking conceptual difficulties in physics teaching [17], interrogating difficult chemistry concepts [18], examining the link between theory and practice in fluid mechanics [19], and analyzing engineering problem solving [20]. Most of this initial research used the dimension of Semantics to differentiate between strengths of context-dependency (semantic gravity) and/or of complexity (semantic density). In the research site in question, the ‘semantic wave’—common currency for theory–practice linking strategies that can lead to cumulative knowledge building [13]—has been used to conceptualize the *semantic range* between abstract, context-independent concepts and specific context-dependent examples. By explicitly unpacking the different levels in a particular disciplinary semantic range, a number of engineering educators have been able to structure their teaching across a particular course or sequence of courses in such a manner as to build a *semantic wave* intended to enable cumulative learning. Table 1 illustrates the use of Semantics in a number of engineering case studies:

Table 1. Modification of existing semantic range examples based on [21].

Semantic Range	Levels of Meaning	Civil Engineering	Process Engineering	Mechanical Engineering
Weaker semantic gravity	Principle	Structural forces determining bracing	Conservation of mass and energy	Principle of projection
	Formula and Calculations	$C_r = \emptyset Af_y (1 + \lambda^{2n})^{(-1/n)}$	Mathematical expressions of process control	First and third angle projection
	Representation	Technical schematic drawings	Block diagram schematic of process control	Orthographic drawing showing different views of an object
	Model	3D/Simulations of structural behavior	Software simulation system	CAD model of the object (orthographic views derived from the model)
Stronger semantic gravity	Real	Physical structure (real building)	Physical process control systems	Physical object

Although the semantic range in the given examples enables a view of particular higher-order concepts and general formulae, as we move down the range, the potential representations, models, and physical contexts actually begin to proliferate. In order to design a richer cumulative learning experience that addresses the need to encourage more open-ended problem solving, engineering educators in the research context have added a second LCT dimension to their repertoire, one that enables the simultaneous view of multiple possible contexts. The LCT Specialization dimension offers insights into forms of knowledge (epistemic relations) and kinds of knowers (social relations). Researchers in the Faculty have used the latter, for example, to analyze how engineering educators ‘build’ kinds of ‘knowers’ [22]—in other words, how the field interprets and applies the development of engineering expertise. For the purpose of this paper, we will now focus on the epistemic plane, which enables a view of the relationship between phenomena and their approaches—the so-called *what* and *how* of knowledge practices.

The epistemic plane (shown in Figure 1) differentiates between strengths of ontic relations (the identity of a phenomenon) and discursive relations (procedures for approaching a phenomenon). Represented as a Cartesian plane, the epistemic plane reveals four quadrants with which to differentiate between practices requiring different *insights* or knowledge-practice codes:

- *Purist insight* is required where a phenomenon has strong ontic relations (universally accepted identity) and strong discursive relations (a standardized approach);
- *Doctrinal insight* describes practices where the approach or procedure takes precedence, such as the rules of the scientific method or differentiation in Calculus;
- *Situational insight* denotes practices dictated by phenomena with strong ontic relations, but where the discursive relations are weaker (there are more possibilities and open-ended approaches);
- *No/Knower insight* is evident when a practice is either ‘anything goes’ or not determined by knowledge, but rather *knowers* (or social relations) [13].

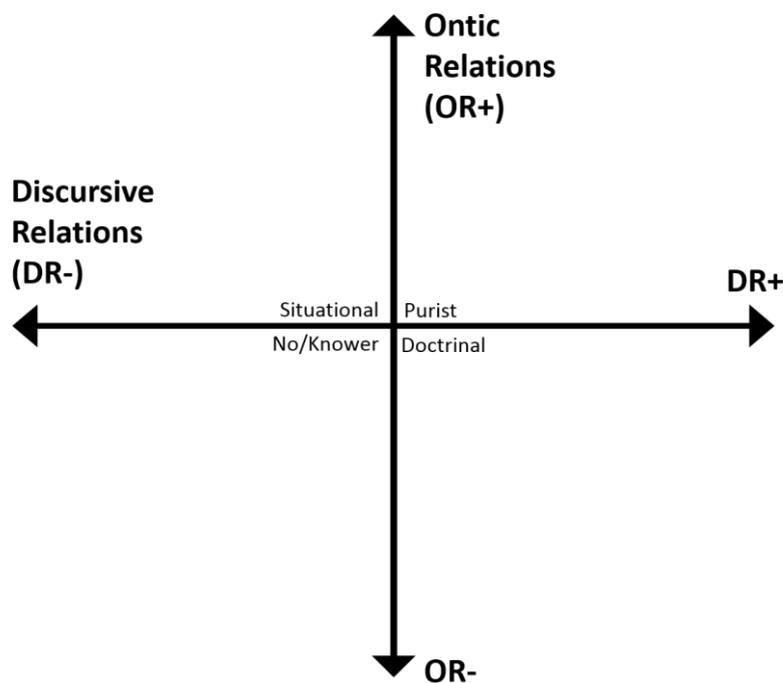


Figure 1. The epistemic plane, from [13], showing the four quadrants determined by relative strength of ontic and discursive relations. Reproduced with permission [13].

There is no right or wrong insight or quadrant. Each insight—as with problem-solving tools—is merely a means to an end. Recent industrial research using the epistemic plane has indicated that successful engineering practitioners navigate the plane in a nonlinear, iterative fashion drawing on different insights as the different contexts demand [23]. In other words, successful engineers practice ‘code shifting’ (the movement between the quadrants) [13], and the question is whether or not higher education is in fact facilitating adequate code-shifting practices during coursework, simulating what is needed in engineering practice.

3. Research Context

This discussion is situated within the experiences of a four-year chemical engineering degree program at a research-intensive traditional university in South Africa. The program is aligned to the International Engineering Alliance standards and accredited by the Engineering Council of South Africa, which is a signatory of the Washington accord. The fluid mechanics course is in the second year, second semester, and aims to instruct students in the fundamentals of fluid mechanics, for

application in chemical engineering specifically. The course deals both with conceptual, abstract topics such as the Navier–Stokes equations, and how to manipulate and use them, as well as more practical calculations and topics, for example, pressure drop calculations, design and calculations around piping networks and pump sizing. While there are context and societally-specific aspects within this program, research conducted with these cohorts is likely to be broadly applicable to other global institutions and engineering programs.

The department in which this course is situated runs a number of educator development programs and initiatives, which are facilitated through the Faculty of Engineering. Several of the lecturers are active contributors to the educational literature, and a common sociological tool (in LCT) is shared as a language of analysis by these researchers. Further, as in most departments, a healthy vibrant discussion of educational practices, experiences, shortcomings, and effects is both apparent and encouraged. This continuing space for co-discussion has allowed for a more longitudinally oriented focus to educational initiatives—initiatives are put in place (for instance, in second-year fluid mechanics), but are not only evaluated in that course; these cohorts of students are followed until (and after) final year, and insights into their continued development can be garnered from these discussions.

Feedback from engineering-related industries suggests that graduates consistently have difficulties ‘applying theory’ [24] and adapting to technical workplace requirements (manpower.com, 2015). This supports the well-reported science–engineering disjuncture [25], which has led to such poor retention rates on engineering programs. Despite the holistic intention of the IEA engineering graduate competency profiles [5], the engineering curricula at research-intensive institutions are predominantly framed by the now 150-year-old science-based tradition [26]. In other words, the core curriculum is interpreted as requiring *purist insight*: well-known and established phenomena with standardized approaches. Large class sizes, a lack of adequate human and technical resources, and undergraduates not adequately prepared for the transition into tertiary levels of study have meant that traditional, assessment-driven pedagogies requiring doctrinal insight remain the status quo, with a great deal of work focusing on computational application.

Higher education practices limited to the right-hand side of the epistemic plane are in stark contrast to the insights that the industry demands of graduates, such as curiosity, agility, and collaboration [27]. These attributes are seldom explicitly taught or encouraged, particularly in the research context in question. The global endeavor to address Sustainable Development Goals requires engineers who are flexible and adaptable, and who are able to engage with stakeholders in multiple, complex sociotechnical contexts. Problem-solving or critical-thinking engineering professionals are those who are able to code shift: to draw on fundamental principles (*purist insight*) and apply standardized methodologies (*doctrinal insight*) in multiple contexts that require situational and knower insights.

In response to student feedback (including observations of student frustrations at being restricted to purist and doctrinal insights), a number of educators in the department have begun to include code-shifting strategies in their classrooms. A collaborative initiative to develop unit conversion and estimation competencies among first-year Chemical Engineering students has seen the establishment of an online question bank explicitly designed using the epistemic plane to encourage students to code-shift between what a unit represents (*purist insight*), how it is converted (*doctrinal insight*) and locally, contextualized estimation challenges (*situational* and *knower insights*) [28]. Another study with final-year students sought to introduce students to a range of contextual examples of core principles and procedures as applied in various mining and metallurgy industries [21]. The same authors went on to examine the third and fourth-year curriculum using the epistemic plane (Figure 2) and found the majority of courses foreground *purist* and *doctrinal insights* [29]. Here, we have amended their figure to include a plotting of fluid mechanics in comparison to other, later-year courses.

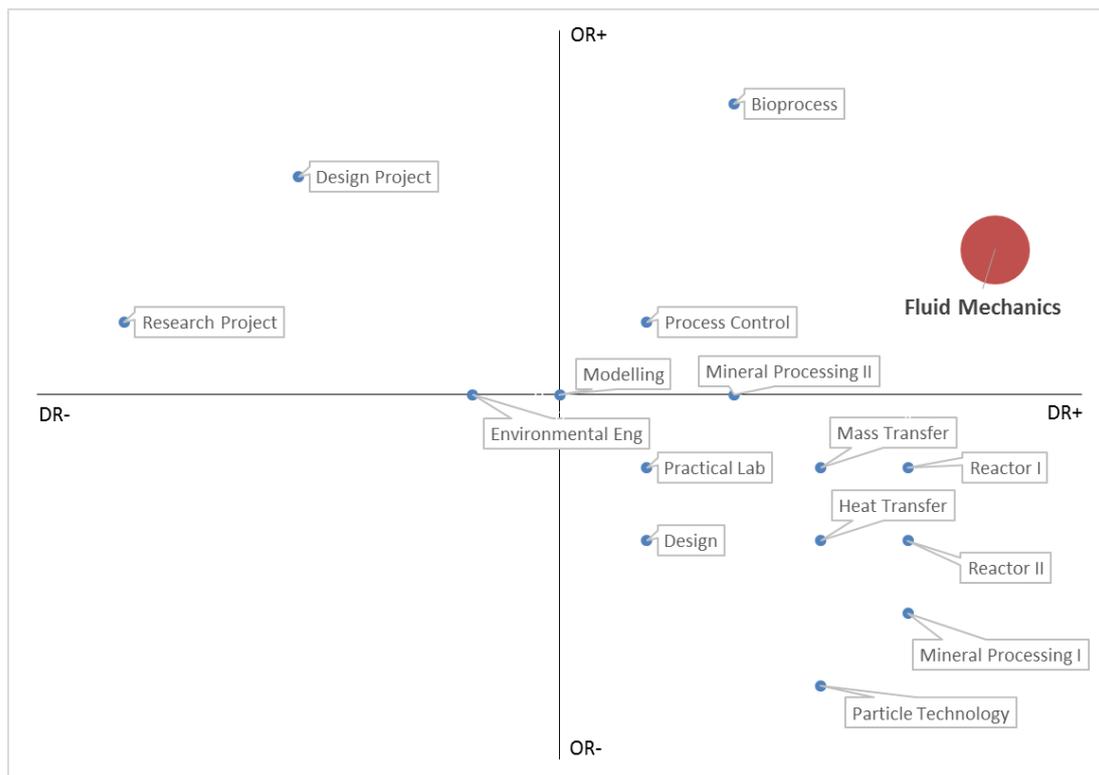


Figure 2. Modified from [29], plot of course content and approach on the epistemic plane for several third and fourth year chemical engineering courses, as well as second-year fluid mechanics. Reproduced with permission [29].

4. Analysis of Fluids Mechanics Using the Epistemic Plane

The major focus of this article is to introduce fluids educators, and engineering educators more generally, to the sociological tool of Legitimation Code Theory, through a demonstration of its usefulness in analysing course activities in fluid mechanics. Let us use an analogy here, for context: say you were to perform a catalysis experiment. In order to measure the extent of reaction, you would take samples and have these analyzed, perhaps on a gas chromatograph or using some other analysis method. What we propose here is that LCT is that analysis method—the tool by which we measure whether our experimentis working.

To achieve a demonstration of LCT's use as an analysis method, the fluid mechanics course will here be broken down into activities—lectures, tutorials, assessments, practicals, assignments, and discussion—and each of these will be analyzed using the lens of LCT, specifically the epistemic plane. A comparison against the transversal of the epistemic plane in industrial application will be presented as a foil to illustrate the gap between the course and its intended site of application.

4.1. Lectures

For the most part, lectures are dialectic discussions of high-level concepts that are occasionally brought down to the level of example or calculation. As such, they sit firmly in the *purist insight quadrant* (Figure 3)—the things being discussed are well defined and the methodology employed to solve the same are well defined and constrained. There may be occasional threads pulled from the situational insight quadrant (for instance, the lecturer may ask, “How could we decide on the pump requirements for a particular reactor configuration?”; the ontic relations are stronger, as in ‘well defined’ (the system), but the approach may be many-fold). There is generally little discussion that could be considered in the *Knower insight quadrant*—the type of person performing the calculations is not foregrounded.

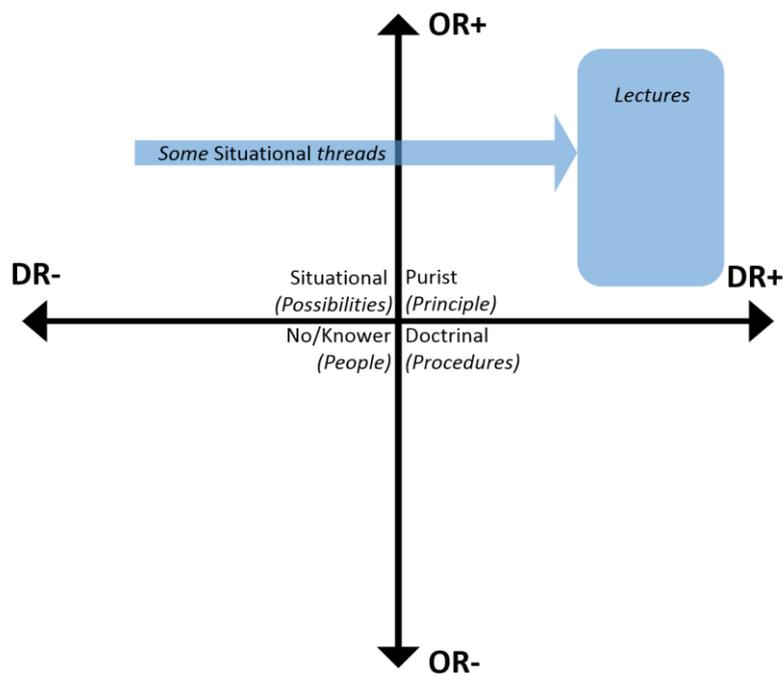


Figure 3. Epistemic plane detailing ontic and discursive movement within fluid mechanics lectures.

Educators will recognize that attending lectures is not sufficient for excellent learning—perhaps stemming from the relatively stationary situation within the *purist insight quadrant* (although there is clearly more to it than presentation without context). Dale [30] espoused the use of multiple media and then solid application to lead to a solid knowledge base, and perhaps a similar argument could be made here. For this reason, it is common to follow lectures with a weekly tutorial.

4.2. Tutorials

Tutorials are a space in which students are given a number of problems and questions to work through, while the lecturer and student assistants (usually post-graduate students) roam the room to answer questions. From the students’ perspective, this for the most part sits within the *doctrinal insight quadrant*—there is much “recognize and reproduce”, with students seeking cues from previously done examples. However, with appropriate question setting, some motion toward the *purist insight quadrant* can be achieved. This occurs when the students do not simply recognize the ‘shape’ of the question and impose an algorithmic approach to problem solving, but rather recognize the underlying principles and their relevance to each question.

A recurring issue during undergraduate engineering education is students’ adopting a superficial learning route to problem solving through ‘pattern recognition’ [31,32]. Students can hide behind recognizing the pattern of the algorithm, rather than grappling with (and therefore undergoing ‘cumulative learning’ [6]) fundamentals. Superficial learning methods can give rise to ‘correct answers’ but shallow understanding. Within the epistemic plane (Figure 4), this represents a narrow transversal between the *doctrinal* and *purist insight quadrants*. Then, what is perhaps needed is some motion toward the situational insights—where students are required to pull on the range of tools they have learned, select one, and apply it to a defined problem.

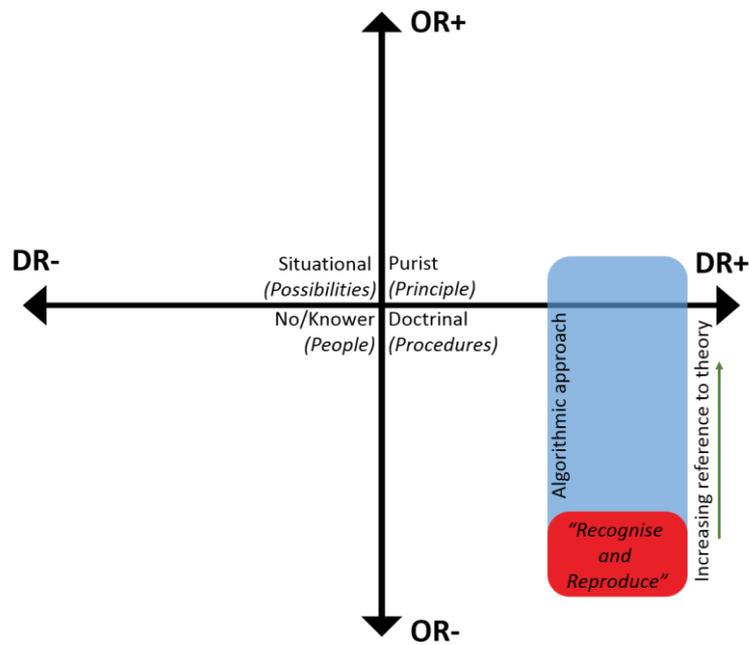


Figure 4. Epistemic plane detailing ontic and discursive movement within fluid mechanics tutorials.

4.3. Practicals

One method to pull students both toward a more situational insight as well as strengthen the semantic gravity of concepts (see [19]) is through the use of practicals. In an ideal situation, students would be presented with an open-ended task or experiment (*situational insight*), in which they would then need to employ the theory (*purist insight*) and calculation ability (*doctrinal insight*) to solve. Thus, they would be traversing a significant portion of the epistemic plane (depicted in Figure 5) and potentially improving their knowledge through the exercise. Further, if there is group work involved, then there may be some development of ‘soft skills’, which require *knower insight*.

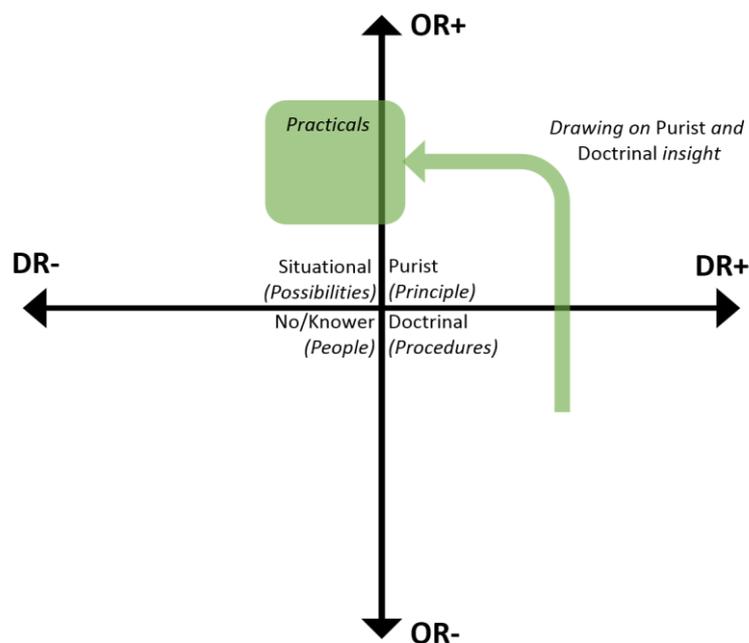


Figure 5. Epistemic plane detailing ontic and discursive movement within fluid mechanics practicals under good conditions.

However, as is discussed in [19,33,34], practicals can often become much less active than envisioned in the above figure. Students frequently do little preparation for practicals (i.e., they do not perform the tour through the *purist insight* quadrant). They will frequently arrive and follow the practical experimental procedure with little or no understanding or insight. This is possible in many practicals due to large class numbers using limited equipment under significant time constraints. In this case, the experience of the students is either a *doctrinal insight* one (where calculations are performed almost by rote), or even devolving into *no insight*, where little learning is taking place, as illustrated in Figure 6.

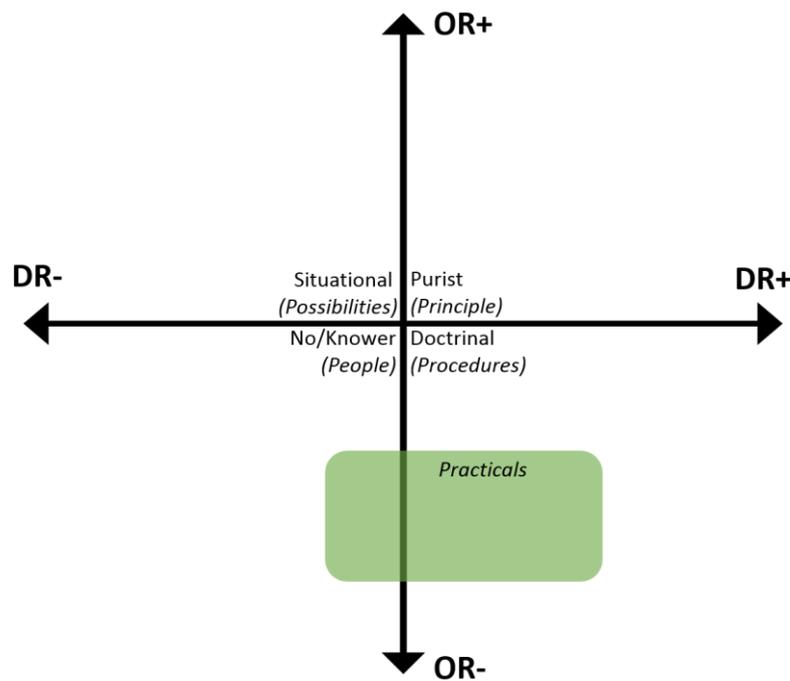


Figure 6. Epistemic plane detailing ontic and discursive movement within fluid mechanics practicals under poor conditions.

An understanding of this shift from a useful exercise to a wasted effort could allow educators to put in place mechanisms stimulating the sorts of desirable activities that lead to real cumulative learning while discouraging the wasted effort of poor learning. For instance, putting in place a pre-practical test to determine whether a student has engaged with the theoretical content that would allow them to understand the practical they are about to do may prevent a weakly epistemically underpinned afternoon in the laboratory.

4.4. Assignment

An assignment is another area where an open-ended, significantly situational problem can be posed, allowing the students to spend time exploring the various possible routes to solutions (a *situational insight*), and once a methodology is arrived at, solving the problem using *purist* and *doctrinal insights*. An example of such an assignment could be to design a piping network and select an appropriate pump for a molasses plant (see the supplementary information for the full assignment). In this case, the problem is an open one, although it is partially bounded by the requirement for piping and pump selection. There are a number of approaches that students could take to solve this (fairly well-defined) problem (*situational insight*). In order to solve it well, they will need to pull on explicitly covered material (calculate frictional pressure losses, use pump characteristic curves to choose an appropriate pump), thus pulling them through *purist* and *doctrinal insight quadrants*, as they conceive of the correct approach and perform the appropriate calculations through a route such as that illustrated in Figure 7.

However, there are other concepts that they need to consider in the assignment that are not explicitly part of the fluids curriculum; these include questions such as, “Will the fluid corrode the piping material? Is there a seasonal variation in flow rates? Is the effect of temperature significant, and if it is, how do we mitigate against this? Is the pump I have chosen very expensive or not available?” These questions pull the student deeper into the *situational insight quadrant*, and as shall be discussed below, deeper into the realm of where real-life engineering problem solving often lies.

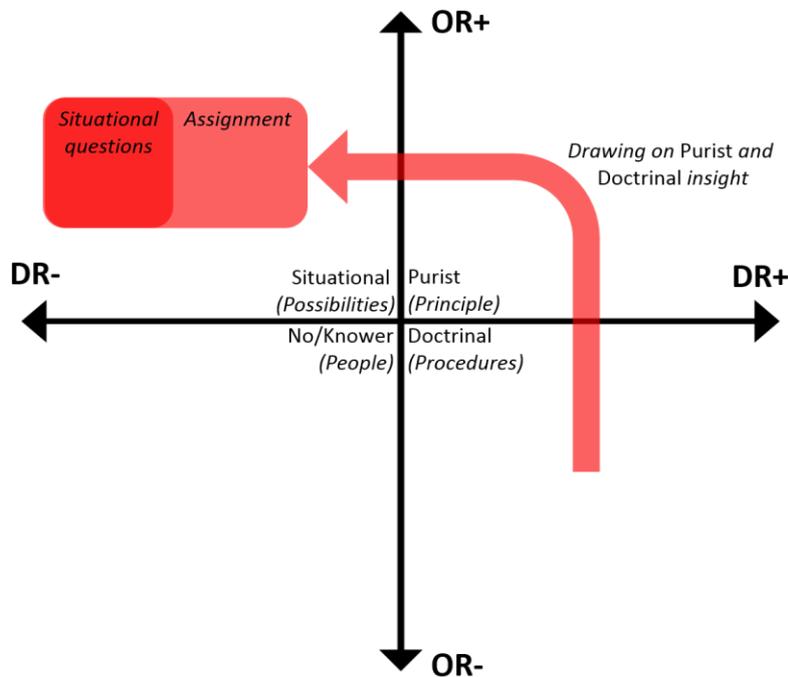


Figure 7. Epistemic plane detailing ontic and discursive movement within a fluid mechanics assignment.

At this point, the reader might be tempted to say that since a full tour of the epistemic plane has taken place through the sum of the course, then we might assume that cumulative learning has taken place. Of course, the answer is more complex than this, since students can successfully complete all required tasks and pass the course with comparatively little long-term learning having taken place (as evidenced in later years where students are unable to make reasonable judgments about pump and piping networks, for instance, in their final-year design module). However, it appears that through a more intentional pursuit of epistemic touring through course structure, student knowledge retention, interest, and focus is improved [19,28,29].

4.5. Application in the World of Work

Having examined some of the significant contact portions of a fluid mechanics course, how does this compare with the real-world application of fluid mechanics in, for instance, a design house? A significant portion of what employers consider important requires *knower insight*: teamwork, communication, ethics, and other ‘soft skills’. The problems presented to working engineers are firmly within the situational insight quadrant; questions such as, “We have wastewater that needs treating; what should we do?” Clearly, there are multiple routes to a solution here, even though the problem in question is a specific one. In order to solve it, design engineers pull on detailed knowledge of specific methodologies, and test their applicability and suitability (*purist insight*). These separate portions of the job are bridged in technical communication, and product design specifically focused on the customers’ requirements.

It is clear from Figure 8 that a significant portion of what is needed in industry is focused on the left-hand side of this plane, while teaching and learning in lectures and tutorials (the primary

modes of learning) are almost entirely on the right. This code clash [13] may be one of the reasons for industry’s (and recent graduates’) complaints that graduates are not sufficiently prepared for the world of work [35,36]. However, it cannot be the case that educators address all of these concepts in every course. It is the role of the overall curriculum to ensure that sufficient opportunities are created across a program to allow for scaffolded code-shifting. Visualizing the existing dominant codes and clashes or mismatches is a necessary first step. It provides an opportunity for designing progressive pedagogies and interventions that bridge these gaps and improve the potential for substantive cumulative learning.

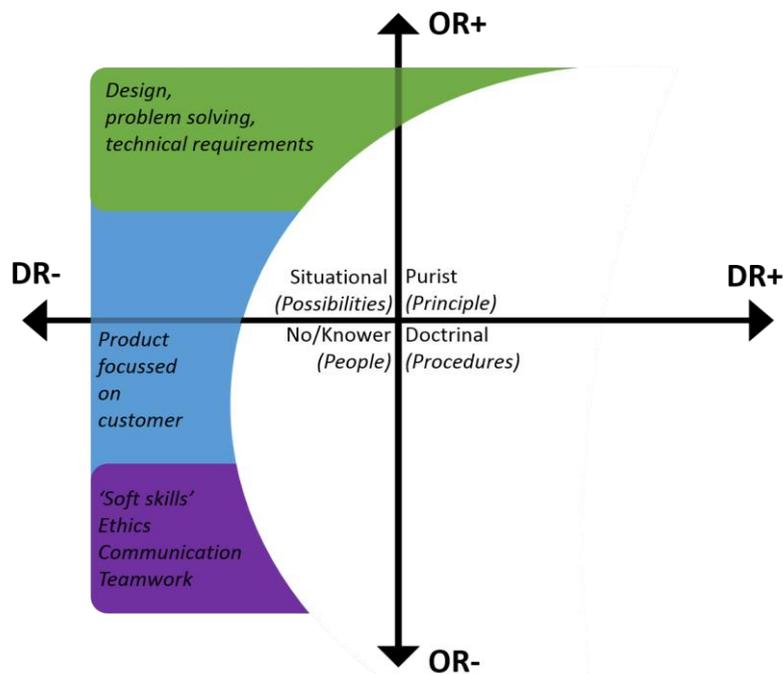


Figure 8. Epistemic plane detailing ontic and discursive movement within the world of work.

5. Conclusions

This paper has set out to illustrate the application of a theoretically informed approach to analyzing an engineering curriculum and pedagogic practices. Focusing on the student learning experience in fluid mechanics at a traditional research-intensive university, the Legitimation Code Theory dimension of Specialization (Epistemic Relations) has been used to demonstrate possible code-shifting strategies that can facilitate the cumulative knowledge building necessary for engineering graduates in complex 21st-century contexts. The analysis was driven by experiences in teaching fluid mechanics and follow-up discussions with colleagues and students regarding knowledge and skill retention beyond the course in question through the degree and post-graduation. The benefit of LCT beyond the course context is its illustrative power in allowing the conceptualization and graphing of educationally lived experience versus intended or needed experience. This may allow educators to consider a priori the potential effects and impact of proposed interventions in progressive pedagogy.

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