

RESEARCH

Teaching, Learning, and Employing Analytical Frameworks as Performance: Analysis of a Quantitative Literacy Event in Applied Mechanics

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Quantitative literacy is the ability to solve problems using mathematical and statistical information that is represented in various forms, including visual, written and mathematical forms. It is central to many of the disciplines within higher education. In this paper, we examine a particular quantitative literacy event within an undergraduate applied mechanics module and, in so doing, argue that teaching and learning are cultural performances of individuals' relations to, in this case, quantitative literacy. Furthermore, we apply a framework for analysing the quantitative literacy demands present within higher education. By applying this framework in a critically reflexive manner, we demonstrate how the researcher similarly engages in a cultural performance in relation to quantitative literacy. We use this anecdotal example to argue that the application of analytical frameworks is inherently performative in nature, and propose the need for a meta-frame for understanding teaching, learning, and the frameworks through which they are viewed, as performance. This has implications for higher education more broadly in that, we argue, the frameworks used promote particular relations to lived teaching and learning experiences, and position teachers, learners, researchers and curriculum developers in particular ways.

Keywords: quantitative literacy; teaching and learning; performativity; higher education; multimodal social semiotics; analytical frameworks

Introduction

Barton and Hamilton (2000: 8) describe literacy *practices* as 'the general cultural ways of utilizing written language which people draw upon in their lives. In the simplest sense, literacy practices are what people do with literacy'. As products of culture, literacy practices are everyday performances of cultural values and social and professional roles. At the same time, these performances take place through representational modes that extend beyond written language: a multitude of representational forms constitute these cultural performances (Kress, 2000). Thus, the notion of 'literacy' needs to be expanded to include the full gamut of representational modes. With this in mind, literacy *events* are concrete instantiations of literacy practices (Barton and Hamilton, 2000). They are the specific performances in which individuals undertake social action. In higher education, one of the primary domains for such events and practices is that of quantitative literacy (or numeracy as it also termed).

This paper provides an example of a particular quantitative literacy event within an applied mechanics module, and uses this example to demonstrate how both teaching

and learning can be seen to be particular cultural performances of, in this case, individuals' relations to quantitative literacy. Furthermore, the paper applies a framework for analysing the quantitative literacy demands present within the particular event analysed. In applying this framework in a critically reflexive manner, we demonstrate how the researcher similarly engages in a cultural performance in relation to quantitative literacy. In so doing, we argue that the application of analytical frameworks is inherently performative in nature. We propose the need for a meta-frame for understanding teaching and learning, and the frameworks through which they are viewed, as performance. Such a meta-frame, we argue, raises the possibility of stepping outside of the dominant discourses of higher education, and science in particular, so as to see how these discourses work to privilege certain values and norms at the expense of others.

This paper is structured such that it begins with a general discussion of the concept of quantitative literacy. Thereafter, we discuss our view of teaching and learning as performance, before introducing a particular framework for understanding quantitative literacy, which is then applied to a specific quantitative literacy event. Finally, we step outside of both the event and the framework by incorporating discussion of the lived teaching and learning event. This allows us to situate both the event, and the

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framework, as a teaching and learning performance. The implications hereof are then discussed. It should be noted that the argument of this paper is a theoretical one and the example drawn upon is illustrative: it should thus be seen as anecdotal rather than empirical.

What is Quantitative Literacy?

There is ongoing debate about what constitutes quantitative literacy, especially in England and Australia (where it is usually referred to as 'numeracy') and in the United States (where it is usually called 'quantitative literacy'). One aspect of this debate concerns the relationship between quantitative literacy and mathematics. Hughes-Hallett (2001: 94) sums up the difference between these two fields as follows: 'mathematics focuses on climbing the ladder of abstraction while quantitative literacy clings to context. Mathematics is about general principles that can be applied in a range of contexts; quantitative literacy is about seeing every context through a quantitative lens'. Orrill (2001: xviii) contends that 'unlike mathematics, numeracy does not so much lead upward in an ascending pursuit of abstraction as it moves outward toward an ever-richer engagement with life's diverse contexts and situations' (Orrill, 2001: xviii). As such, quantitative literacy does not limit the mathematics and statistics involved, as explained by Johnston (1994: 34):

There is not a particular level of Mathematics associated with it: it is as important for an engineer to be numerate as it is for a primary school child, a parent, a car driver or a gardener. The different contexts will require different Mathematics to be activated and engaged in.

In the South African school context, the subject *Mathematical Literacy* comprises the same kinds of mathematical and statistical competencies as quantitative literacy. This subject is defined as 'a subject driven by life-related applications of mathematics' (Department of Education, 2003: 9). While word problems and standardized test items are often designed to approximate real situations, when they are used in educational settings they are generally structured so that they have only one correct answer. This is especially evident when items are presented in a multiple-choice format. As such, these tasks might be considered 'realistic' but are far from 'real'.

Some authors, ourselves included, prefer to take an academic literacies approach and conceptualize quantitative literacy as a social practice (Street, 2005; Street and Baker, 2006; Chapman and Lee, 1990). Others, however, focus on those aspects of quantitative literacy that have to do with thinking critically about the use of numbers in society (Johnston, 2007). Regardless, these varying definitions of quantitative literacy all emphasize a fundamental concern with mathematics and statistics used in context: at the very least then, the definitions garnered from this debate would agree that quantitative literacy is to do with 'using maths in context' and that to be numerate is to have the 'capacity to use maths effectively in context' (Johnston, 2002: 4). It follows, therefore, that quantitative

literacy cannot be seen as a generic skill and that quantitative literacy events cannot be approached using learned rules. Thus, in almost all cases, the application of quantitative methods and reasoning within 'realistic' contexts is a feature of our view of quantitative literacy.

We use the terms 'practices' and 'events', as put forward by Barton and Hamilton (2000), to discuss the notion of quantitative literacy. Centrally, we are concerned with the practices in which these competencies are required. 'Practice' offers a way of linking semiosis with what individuals as socially-situated actors do, both at the level of the context of a specific situation and at the level of the context of culture. The term 'practice' is defined as 'habitualised ways, tied to particular times and places, in which people apply resources (material or symbolic) to act together in the world' (Chouliaraki and Fairclough, 1999: 21). Bourdieu (1977: 78) suggests that a practice is an action with a history. This notion of 'practice' has been applied to quantitative literacy by a number of theorists such as Street (2000, 2005) and Baynham and Baker (2002). For these theorists, quantitative literacy practices are:

More than the behaviours that occur when people 'do' mathematics/numeracy, more than the events in which numerical activity is involved, and so enable the conceptualizations, the discourses, the values and beliefs and the social relations that surround numeracy events as well as the contexts in which they are sited to be explored (Baynham and Baker 2002: 6).

As opposed to a skills-based view of student learning, a practices view is not a deficit view. In curriculum design, for example, looking at numeracy as a social practice could potentially be a way of including aspects that have traditionally been side-lined in mainstream curricula, such as indigenous knowledge systems and ethnomathematics, for instance. This raises the possibility of more inclusive higher education curricula.

To conclude this section, therefore, the definition of quantitative literacy that informs this paper is as follows:

Quantitative literacy is the ability to manage situations or solve problems in practice, and involves responding to quantitative (mathematical and statistical) information that may be presented verbally, graphically, in tabular or symbolic form; it requires the activation of a range of enabling knowledge, behaviours and processes and it can be observed when it is expressed in the form of a communication, in written, oral or visual mode. (Frith and Prince, 2006: 30)

We view these expressions (whether in written, oral or visual mode) as quantitative literacy 'events', and these events as concrete instantiations of quantitative literacy practices (Barton and Hamilton, 2000). That is, quantitative literacy practices become manifest through quantitative literacy events, in which participants 'perform' their

understandings of and relations to quantitative literacy and the social practices of which it forms part. In this paper, we attempt to further debate about redistribution, representation and recognition (Fraser, 2009) in higher education by examining teaching and learning events, as well as the frameworks used to analyse them, within a 'performance' perspective, to which we now turn.

Teaching and Learning as Performance

Our conception of teaching and learning as performance is different from, but implicated in, notions of performativity. Performativity is part of what Macfarlane characterises as a broader performative turn within society and refers to 'evaluations and performance indicators connected with the measurement of teaching and research quality' (Macfarlane, 2015: 338). For teachers, this is associated with increasing use of administrative tools aimed at evaluating how teachers perform (Falter, 2016), such as teaching evaluations, performance assessments and so on. For students, it is associated with increasing use of learning outcomes, attendance registers, and assessment (Macfarlane, 2015). However, our concern is with 'the tacit dimension of teaching, where teachers draw on experience, on trial and error over time, to arrive at proven routines that work' (Lewis, 2013: 1028). The notion of performance does not mean that teaching involves certain theatrical techniques, or that the classroom is a stage; rather, it implies that teaching (and learning) is performed scholarship (Falter, 2016). It means that curriculum is delivered through a pedagogy of enactment, that is, that curriculum is enacted through pedagogy (Lewis, 2013). As such, the idea that teaching and learning are performance reclaims the notion of 'performance', situating it in the daily realities inside and outside of classrooms and subverting notions of 'performance management' (Falter, 2016). Whereas performativity is the antithesis of creativity in that it promotes a single 'right' answer mentality, the notion of performance offers the possibility to go 'off script', so to speak (Falter, 2016).

Such a view of teaching and learning as performance allows us to locate teaching as a multimodal activity and emphasise the particular, embodied nature of teaching. In this regard, our use of performance is metaphorically akin to its use in the theatrical sense. Understanding teaching as performance allows for consideration of the 'verbal processes and techniques used by teachers to enact curriculum and manage classrooms' (Morgan-Fleming, 1999: 287), but also moves beyond what teachers say, and includes all aspects of their performance, and how each of these aspects carries meaning in the context of the classroom. Within such a view, the teacher's body is productive of meaning (Falter, 2016), in that voice, gesture and body movement are all important signs within teaching activity (Lewis, 2013). However, the classroom as a whole is also productive of meaning. The classroom is an assemblage of social and material aspects (Riveros and Viczko, 2015) that shape (and are shaped by) the performance. Furthermore, technological tools are put to use within classrooms, and these further shape teaching and learning performances and are themselves shaped through these performances

(Riveros and Viczko, 2015). For example, Jewitt, Moss and Cardini (2007) examine how Interactive White Boards used in school mathematics classrooms configure pedagogy in both positive and negative ways. A view of teaching and learning as performance thus shifts the focus from the teacher as sole 'actor' and gives attention to all other actors, including the non-human actors, within the performance (Riveros and Viczko, 2015).

Given the multimodal nature of this view of teaching and learning, there is an inherent concern with emergent text forms. Different kinds of texts enact social practices in different ways. By way of example, Riveros and Viczko (2015) show how the concept of anaemia is 'performed' differently through different practices that are made manifest through different types of text. In the doctors' rooms, a clinical performance is enacted whereas in the laboratory, a statistical performance is enacted. In the former, the concern is with examination of symptoms through various means where such examination takes place through interpersonal, bodily interaction. In the latter, the concern is with counting haemoglobin, which takes place through the use of advanced technologies and the preparation of laboratory test results. We include this example to make the point that higher education often ties its participants to certain textual performances, thus limiting opportunities for 'improvisational and creative performance [that] allows an opportunity for teachers [and, we would argue, students] to resist and play' (Falter, 2016: 32). As such, the emergence of new text forms opens up possibilities for re-enacting social practices and introducing new curricular performances, for both lecturers and students.

Our view of teaching and learning as performance also enables consideration of how educational policy, standardised curricula, assessment and teacher evaluation come to inform teaching and learning performances. As Morgan-Fleming (1999) argues, teaching is more than 'thinking about teaching' or 'writing about teaching', and teachers should be evaluated on the basis of their ability to *perform* teaching through interaction with students. However, the in-class performances of teachers are (increasingly) often encroached upon by broader policy and curriculum directives (Falter, 2016). For example, large-scale, standardised tests of student achievement increasingly shape educational practice. Teaching and learning performances come to enact these assessment expectations, shifting the roles of the human and non-human performers and, at the same time, validating specific forms of learning, teaching and knowledge at the expense of others (Riveros and Viczko, 2015).

In the science and engineering disciplines, in which this paper is located, there is increasing focus on the achievement of learning outcomes and the development of graduate attributes. These outcomes and attributes enact what it means to perform as a part of the 'flexible professional class' (Addison, 2014: 314), but ignore the fact that being a professional involves enacting ways of being that are always open-ended, incomplete, dynamic and occurring along diverse trajectories (Riveros and Viczko, 2015). But, teaching and learning are not mechanistic enactments of policy. Instead, teaching performs these material realities

by recontextualising and transforming them (Riveros and Viczko, 2015). These performances fall into two types: those that remain heavily scripted by content and curriculum, and those that are more flexible, in which teacher and student jointly enact pedagogy (Falter, 2016). As such, alternative pedagogies that encourage dialogic, situated practice can counter technocratic narratives and include broader performances of professionalism (Addison, 2014). As Addison continues, learning outcomes are not simply achieved: they are performed and, because each performance is slightly different, transformed. As such, teaching and learning have 'performative power' (Falter, 2016).

Of course, learning is as much a performance as is teaching. Macfarlane (2015) has argued that there is enormous pressure on students within higher education to 'conform' by engaging in valued performances of learning. Archer et al. (2017) show how science classrooms come to be dominated by certain learning performances and the implications this has for the performance of science in schools. Learning is not a passive act; instead it is 'enacted in the socio-material engagements that constitute the practice of teaching' (Riveros and Viczko, 2015: 541). Indeed, to extend the metaphor, the success of a performance depends on its audience: 'the onus is entirely placed on the spectator to be able to remember the performance once it has disappeared and accumulate enough authority through repetition to become an established successful practice' (Falter, 2016: 30). In the classroom, students determine the success of teacher performances and, through assessment, teachers determine the success of student performances. As such, the two are entwined in a dynamic series of performances in which both participate and neither remains passive.

A Framework for Analysing Teaching and Learning in Quantitative Literacy Events

There are various frameworks pertaining to quantitative literacy, mathematical literacy or numeracy, such as the Trends in International Mathematics and Science Study (TIMSS), the Program for International Student Assessment (PISA), and the Adult Literacy and Life skills (ALL) Survey (Gal et al., 2005: 152). In this paper, we apply a quantitative literacy framework initially developed as part of the South African National Benchmark Tests project (Frith and Prince, 2006: 28), but later adapted for more general application (Frith and Prince, 2009: 89). The framework is used to explicate the quantitative literacy practices expected within a particular quantitative literacy event in applied mechanics, undertaken as part of a diploma in civil engineering. The importance of quantitative literacy for higher education in general, and engineering in particular, is widely recognised (see, for example, Steen, 2004), and there is also an increasing awareness that many academic disciplines make complex quantitative demands that are often very different from those that are the focus of traditional mathematics courses. The framework deployed in this paper is presented in **Table 1**. As can be seen, it divides quantitative literacy into six broad competences.

In higher education, there are different quantitative literacy practices associated with different academic

disciplines. These practices are often tacit (Collins, 2001) and are embedded within curricula in implicit ways. Yet, these practices involve the transformation of signs and the formation of new signs and, in so doing, act as traces of learning and support the development of new capabilities (Selander, 2008). In Prince and Archer (2014), the notion of academic voice is used to facilitate awareness and analysis of multimodal texts in order to 'enable student access to the invisible norms and conventions of quantitative disciplines'. The quantitative literacy framework presented in **Table 1** is designed to work across all higher education disciplines and contexts that involve quantitative work and aims to make visible the implicit quantitative demands of higher education. In the section that follows, we apply this framework to a particular quantitative literacy event, focusing on the competences expected of students, as made visible by this framework.

Analysing a Quantitative Literacy Event in an Applied Mechanics Course

The previous section has introduced a framework for understanding quantitative literacy events within the context of higher education. In this section, we apply this framework to a particular quantitative literacy event that took place in an applied mechanics module that formed part of a three-year diploma in civil engineering. The particular event under study took place within the context of a test in which one of the questions required students to calculate the centre of gravity, or centroid, of an irregularly-shaped, composite object. **Figure 1** presents the specific question asked, while **Figure 2** presents part of one student's response to this question. Permission for the use of the student's response was obtained from the student concerned.

A test question such as this requires of students to demonstrate many of the competences identified in the framework. For example, the question requires that students understand various quantitative terms and phrases. Terms such as 'triangular', 'rectangular', 'prism' and 'centroid' carry specific quantitative meanings, and are included in the test question with the specific aim of prompting students to connect the shapes depicted to mathematical formulae, such as the fact that the centroid of a triangular object is located at $\frac{h}{3}$ (which happens to be the mistake that the student whose work is depicted in **Figure 2** makes: the student calculates the centroid of the triangular object as being located at $\frac{h}{2}$). However, the test question shown in **Figure 1** is, clearly, a multimodal text and, in addition to linguistic cues, students are also expected to know and understand the various symbolic conventions depicted. These include symbols for diameter (ϕ), density (ρ), as well as centroids ($\bar{y}$ and $\bar{x}$). Furthermore, the question also incorporates conventionalised visual representations, such as the use of double-headed arrows to depict dimensions.

These various representational modes are meant to be 'read' in conjunction with one another. That is to say, according to the second competence identified in the NBT quantitative literacy framework, students are expected to identify and distinguish connections between

Table 1: Framework for analysing the quantitative literacy demands of higher education (Frith and Prince, 2009: 89).

Competence	Examples/Elaboration
1 Knowing the conventions	This involves knowing the meanings of quantitative terms and phrases, and the mathematical and statistical concepts that these words refer to; it also includes knowledge of systems of units of measurement. This involves knowing the conventions for the symbolic representation of numbers, measurements, variables and operations, for example: – representation of decimal numbers, and – symbols for operations such as exponentiation. This involves knowing the conventions for the representation of data in tables, charts, graphs and diagrams (such as tree diagrams, scale and perspective drawings, and other visual representations of spatial or conceptual entities), for example: – bar, pie, scatter plots, – ways of showing scale on diagrams and maps, and – ways of representing 3D objects in perspective.
2 Identifying and distinguishing	This involves locating the relevant connections between different representations, for example: – locating the parts of a graph referred to in the verbal description of a process which is also represented graphically, – recognising that a table of data and a chart depict the same information, and – noticing significant differences between superficially similar representations. This involves identifying which mathematical concepts or methods are relevant in a context, for example: – knowing which arithmetic operations to perform, and – knowing when to formulate an equation. This involves identifying which information provided is relevant in a particular context, for example: – recognising which parts of a graph or chart contain the needed information, and – identifying misleading or redundant information. This includes understanding a verbal description of a quantitative concept, situation or process. It also involves deriving meaning from representations of contextualized data by, for example: – reading values off a chart, or – observing trends in tabulated data. Finally, it includes deriving meaning from graphical representations of relationships, for example: – using observations of the slope to derive information about rates, – reading off maximum or minimum values from a curve, and – translating between different representations of the same quantitative information.
3 Deriving meaning	This involves using mathematical methods to solve a problem or clarify understanding, for example: – calculating, – modelling a situation algebraically, – finding rates of change, – calculating the slope of a graph, and – solving equations.
4 Doing mathematics	4.1 Using mathematical methods

(Contd.)

Competence		Examples/Elaboration
5 Higher order thinking	5.1 Synthesising	This involves synthesizing information or ideas from more than one source, for example, reading information from a chart and from a table and using them to understand a situation.
	5.2 Logical Reasoning	This involves identifying whether a claim is supported by the available evidence, formulating conclusions that can be made given specific evidence, and identifying the evidence necessary to support a claim.
	5.3 Conjecturing	This involves formulating appropriate questions and conjectures, in order to make sense of quantitative information, and recognizing the tentativeness of conjectures based on insufficient evidence.
	5.4 Interpreting and reflecting or evaluating	This involves interpreting quantitative information in terms of the context in which it is embedded by, for example, interpreting the results of the calculations in the original context.
	6.1 Representing quantitative information using appropriate representational conventions	This includes choosing appropriate representations of quantitative information, and expressing quantitative information in a context: verbally, symbolically, graphically, diagrammatically or in tabular form.
6 Expressing quantitative concepts	6.2 Describing quantitative ideas and relationships using appropriate language	This involves: identifying appropriate/correct descriptions of quantitative ideas, patterns, comparisons, trends, relationships; describing quantitative ideas, patterns, and comparisons between quantities, trends and relationships; and explaining reasoning (by linking evidence and claims).

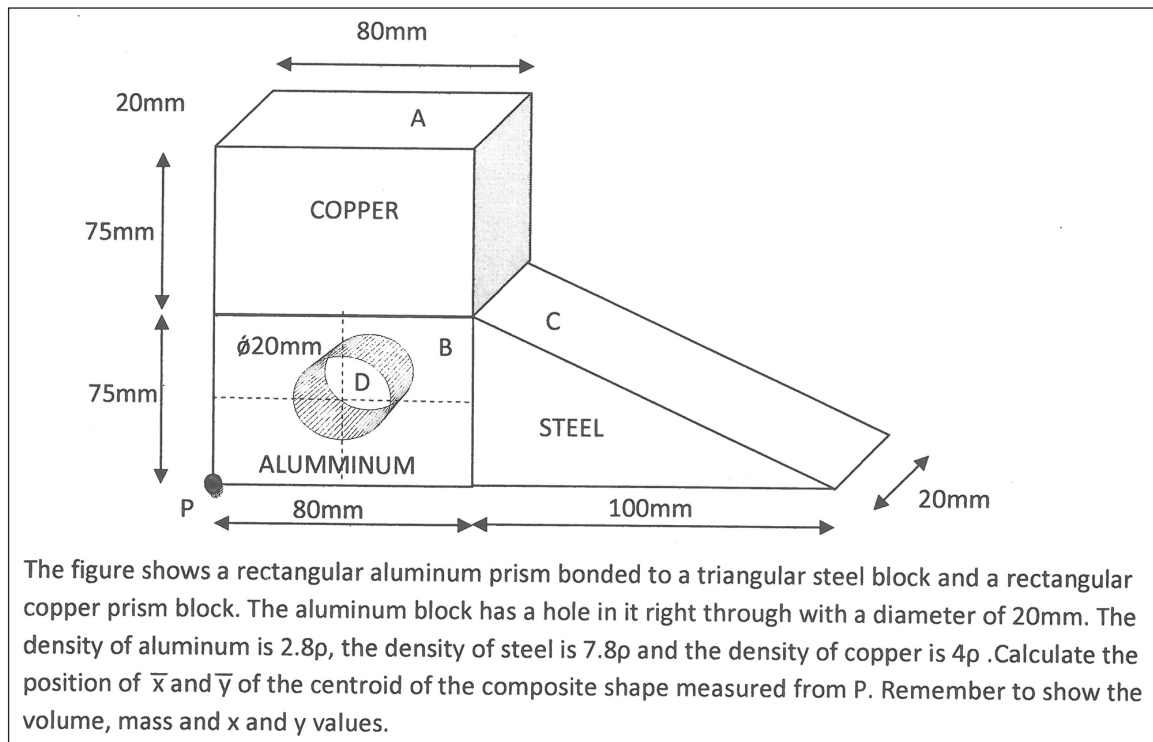


Figure 1: Applied mechanics test question on centroid of a composite object.

$$\bar{x}_{total} = \frac{M_{cop} \bar{x}_{cop} + M_{alum} \bar{x}_{alum} + M_{steel} \bar{x}_{steel} - M_{hole} \bar{x}_{hole}}{M_{total}}$$

$$= \frac{(480000)(40) + (336000)(40) + (585000)(130) - (17592,92)(40)}{1383407,08}$$

$$\bar{x}_{total} = 78,06 \text{ mm}$$

$$\bar{y}_t = \frac{M_{cop} \bar{y}_{cop} + M_{alum} \bar{y}_{alum} + M_{steel} \bar{y}_{steel} - M_{hole} \bar{y}_{hole}}{M_{total}}$$

$$= \frac{(480000)(112,5) + (336000)(37,5) + (585000)(37,5) - (17592,92)(37,5)}{1383407,08}$$

$$\bar{y}_t = 63,52 \text{ mm}$$

Figure 2: Extract of a student answer to applied mechanics test question on centroid of a composite object.

the various components in the question. Specifically, for example, a student would be expected to connect the linguistic notion of 'rectangular aluminium prism' to the visual representation thereof: while the linguistic part of the question attaches a density value to this rectangular section, the visual component provides the dimensions thereof through conventionalised visual representations. As such, in order to successfully answer this question,

students are required to not only know and understand, but also to make connections between the various linguistic, symbolic and visual representations present. Similarly, a student would need to connect the linguistic cue 'hole in it right through' to the visual depiction of the cylindrical hole through the rectangular section, where it is the graphical representation that shows that the centre of this hole coincides with the centre of the rectangular

section. This is indicated, visually, through the use of the dotted lines in the image. In so doing, students also exercise the third aspect of the framework, namely, deriving meaning from graphical representations, and translating between different forms of representation.

Thereafter, students are expected to identify, and undertake, the mathematics that is required in this question, the fourth aspect of the NBT quantitative literacy framework. The required maths is implied in the question, in that it states that students should 'calculate the position of $\bar{x}$ and $\bar{y}$ of the centroid of the composite shape measured from P'. However, this still requires that students are able to engage the correct mathematical tools to complete this task. In this particular example, this means that students need to be able to identify, and use, the following equation:

$$\bar{x} = \frac{m_1\bar{x}_1 + m_2\bar{x}_2 + m_3\bar{x}_3 + \dots + m_n\bar{x}_n}{m_{total}}$$

In this particular assessment question, students are not expected to exercise the fifth aspect of the NBT quantitative literacy framework. This aspect requires that students use the results of mathematical operations to exercise judgment, reason and reflect, and draw conclusions. This question does not require students to use the result in this way. But, students are expected, in the answers they produce, to exercise the final aspect of the framework, namely, to express quantitative concepts themselves. However, for the purposes of this analysis, we believe that examination of the first four aspects of the framework is sufficient to demonstrate the value that such a framework has for unpacking the quantitative literacy practices involved in relatively simple procedures such as this and, indeed, in more complicated procedures.

As we have argued elsewhere (see Prince and Simpson, 2016, for a more detailed application of the framework), the application of frameworks such as this has value in that it 'allows for an understanding of points of disconnection or confusion in the texts that students produce which, in turn, can inform the design of pedagogy that seeks to minimize these points of disconnection' (Prince and Simpson, 2016: 198). However, in the remainder of the present paper, we add a caveat to this point, namely that such frameworks *exclude* certain aspects inasmuch as they *include* important facets. As such, the use thereof should be accompanied by the application of a meta-frame. We make this argument, in the sections that follow, by applying the performance perspective previously described to both the quantitative literacy event presented herein, but also to the framework introduced by Frith and Prince (2009).

Teaching, Learning, and Frameworks as Performance

The framework deployed in the previous section (that of Frith and Prince, 2009) has been used to explicate the specific practices deployed during a particular quantitative literacy event, in this case, the determination of a centroid of a composite object within applied mechanics.

These practices include identification of mathematical functions, knowing the conventions for representing quantitative information, and translating between different modes of representation of quantitative information. However, broader ethnographic observation, in which one of the authors acted as an observer throughout the entire applied mechanics module (as part of a broader study into the social semiotic aspects of engineering education), reveals that in-class teaching and learning activities were integral to the production of these texts. Despite this, these activities are not made visible within the analysis enabled by the NBT Quantitative Literacy framework. Instead, as will be shown, by moving beyond this framework it is possible to understand these texts as part of a narrative in which teaching and learning interact to produce texts as traces of, in this case, applied mechanics knowledge. This demonstrates that teaching and learning performances are not located in particular spaces or within individuals' psychological processes; rather, learning occurs through 'socio-material assemblages' (Riveros and Viczko, 2015). This example, reported on in the remainder of this paper, is drawn from a broader study and is used here merely for illustrative purposes.

In the applied mechanics course, the course lecturer had taught the procedure for calculating centroids prior to the test. In the initial class on this topic, the lecturer introduced the equation given in the previous section. In so doing, she was performing her understanding of the topic of centroids, namely, that centroid problems are solved algebraically using a particular mathematical equation. However, the students left the class feeling confused, the vast majority of them unable to connect the abstract terms given in the algebraic equation to the various elements depicted graphically. The lecturer was aware that the students, by and large, had not been able to successfully grasp this concept. As such, in the subsequent class, she indicated that the students should ignore what had occurred in the previous class, and proceeded to introduce a different method for calculating the centroid of a composite object. This alternative method involved constructing a tabular representation of the various components of the objects and the variables (mass, volume, density and the centroids along each of the x and y axes) at stake in determining the centroid. This tabulated representation supplanted the need for the algebraic equation, allowed students to leverage more of their own semiotic resources, and created a more tangible connection between the visual components and abstract mathematical concepts. This tabular method is shown in **Figure 3**, another student's response to the question posed in **Figure 1**. The students unanimously agreed that the tabular method was a far simpler way of calculating the centroid of a composite object.

This exchange demonstrates two important aspects of performance, as identified by Morgan-Fleming (1999). First, it illustrates the notion of tradition as opposed to innovation. In this example, the lecturer moves away from the abstract equation which is, in the words of Archer et al. (2017), a 'celebrated' performance within mathematics, science and engineering. Morgan-Fleming argues that there is always an interplay between dynamism and

	Volume	Mass	$\bar{x}$	$\bar{y}$
COPPER BLOCK	120000	480000 p	40	112.5
ALUMINIUM BLOCK	120000	336000 p	40	37.5
STEEL TRIANGLE	75000	585000 p	113.333	25
⊖ CYLINDRICAL HOLE	6283.185	(17592.918 p)	40	37.5
		1383407.082 p		
COPPER BLOCK				
ALUMINIUM BLOCK				
	$M \times \bar{x}$	$M \times \bar{y}$		
COPPER BLOCK	19200000 p	54000000 p		
ALUMINIUM BLOCK				
ALUMINIUM BLOCK	13440000 p	12600000 p		
STEEL TRIANGLE	66297805 p	14625000 p		
CYLINDRICAL HOLE	(70376.72 p)	(659734.425 p)		
	98236088.28 p	80565265.58 p		

Figure 3: Extract of a second student's answer to applied mechanics test question on centroid of a composite object.

conservatism when individuals perform their learning: teachers can draw upon traditional instructional practices and techniques, but if these are not taken up by learners, the teaching performance has failed. Here, the lecturer's two different performances were received in radically different ways, showing how performances enact multiple, relational and situated realities (Riveros and Viczko, 2015). Second, this exchange demonstrates the importance of emergent text structures within teaching and learning performances (Morgan-Fleming, 1999). Emergent texts, Morgan-Fleming argues, exist in the middle ground between traditional, scripted performances (such as the lecturer's reliance on the algebraic equation) and completely novel performances. The tabular representation introduced by the lecturer in the second class therefore exists as an emergent text within the frame of the particular content section at stake, namely, centroids of composite objects.

However, the student whose calculations are presented in **Figure 2** has *not* made use of the tabular representation. Instead, he has relied on the application of the algebraic equation initially introduced by the lecturer. The reason for this emerged from subsequent discussion with the student concerned. During this discussion, the student indicated that he had used a past student's test papers to practice for his own tests. Because, in previous years, the lecturer had only used the algebraic equation,

and not the tabular method, previous students had relied solely on the former technique. As such, this student's 'performance' reflects the process he used to study, rather than that which was performed in the classroom.

Again, this student's answer to the given question illustrates important aspects of teaching and learning as performance. In the first instance, it demonstrates that performances of learning do not emerge within a vacuum; instead, they are implicated in wider entanglements of human – and non-human – action (Riveros and Viczko, 2015). They emerge because of the presence of particular artefacts both inside and outside of the classroom, and these artefacts can become significant protagonists in the performance of teaching and learning (Riveros and Viczko, 2015). In the second instance, this example demonstrates that there are performed spaces for learning, but that these spaces exist both inside and outside of classrooms. These spaces interact in a continuous back-and-forth that ultimately informs the multiplicity of the performances that emerge (Riveros and Viczko, 2015). The introduction of new artefacts leads to new performances requiring new translations. As such, teaching and learning can be seen as 'complex and performed assemblages that include a multiplicity of networked actors' (Riveros and Viczko, 2015: 545).

This narrative constitutes the 'back-story' to the test question presented in **Figure 1** and the answer produced

in **Figure 2**. However, this back-story has a material impact on the textual performance created by the student concerned. This demonstrates how teaching and learning are performed on a daily basis by individuals in interaction with each other and with outside influences, both human and non-human. Analytical frameworks, by their very nature, are limited in their ability to capture and account for this complex interaction. While frameworks such as the quantitative literacy framework deployed in this paper are useful for 'performing' certain aspects of a teaching and learning event, they can serve to 'black-box' other aspects. When one applies an analytical framework, one can see more clearly that which is made visible by the framework: in this case, the framework we have used allows us to articulate what practices students need to deploy in order to successfully determine the centroid of a composite object. But, what it does not allow us to see is how teaching and learning performances are concrete instantiations of dynamic processes over time.

Ultimately, therefore, we argue that we also require a meta-frame that elucidates how analytical frameworks fix the performance of teaching and learning in particular ways, as shown in the example above. We see such a meta-frame as one in which the framework itself is conceived of as equally performative in nature as are teaching and learning. Quantitative literacy events such as the centroid example discussed here thus exist at the intersection of how teaching is enacted, how learning is performed, and the framework through which the event is viewed. This notion of the meta-frame is represented in **Figure 4**, and illustrates our understanding of teaching and learning, and frameworks, as performances. **Figure 4** suggests a view in which teaching and learning, and the frameworks through which they are viewed, all exist, equally, as separate from the event itself and as performances thereof. While technical frameworks such as the one described above can be useful for informing teaching and learning, especially its use as a language of description, it also has limitations. These limitations can be ameliorated by the use of a meta-frame such as the one in **Figure 4** in which the view of key aspects of teaching and learning can be

illuminated and foregrounded in order to facilitate effective knowledge creation and its management. The meta-frame allows the observer/researcher to go beyond the framework and take into account aspects of the teaching and learning performance that are not visible through the framework alone.

Moreover, the application of such a meta-frame allows for exploration of how selections (in terms of content, approaches, resources, amongst others) are made, whose interests are served by those selections, and what is at stake in those selections. In the classroom, the performances that teachers produce are often fleeting and, as such, the only measure of the success thereof, is found in the performances that students produce (Falter, 2016). However, the performances produced by students are equally dynamic, and students do not simply, and passively, reproduce performances. Analytical frameworks, in turn, tend to describe what students produce, or what teachers do, and fix this in a moment in time. This, while helpful in one respect, obscures the complex relationship between teaching and learning performances, requiring the application of a meta-frame to interrogate these frameworks.

Implications and Conclusions

The calculation of the centroid of an object is but one among many quantitative literacy practices deployed within science and engineering study. In this paper, we consider this example so as to demonstrate the kinds of quantitative literacy practices deployed within science and engineering education. At the same time, we acknowledge that such quantitative literacy practices are made manifest through specific events in which multiple representational modes (written language, diagrams, and mathematical symbolic notation, among others) are used. These events have been considered through the application of a particular analytical framework for understanding quantitative literacy demands in higher education in South Africa. This framework was useful for explicating the quantitative literacy demands inherent in the exemplar event, as well as the extent to which students are able to meet these demands.

However, the framework fails to account for possibilities of difference in the texts produced by students. For this, we relied upon ethnographic observation of lived teaching and learning events. This observation reveals that the application of a tabulated method for determining the centroid of a composite object was preferred by students, possibly because it was more closely bound to the context of the given problem, in that each row represented an element within the composite object, and each column a characteristic of that element (mass, volume, density and so on). In contrast, the algebraic expression originally taught to the students was far more abstract in its presentation of these aspects, with each reduced solely to symbolic representation. Similarly, it was shown that the progression from teaching to learning is neither linear nor straight-forward. This was evident in the test answer produced by one of the students, who still elected to use the algebraic method for determining the centroid

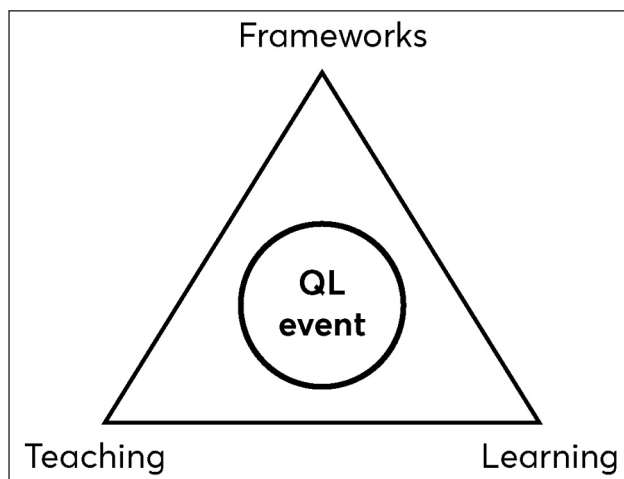


Figure 4: A meta-frame for analysing quantitative literacy events.

of a composite object. The framework applied failed to account for these dynamics, instead examining the performances as isolated texts.

In so doing, we reflected on the limitations of the application of this framework, and frameworks in general. We argue that teaching and learning events are cultural performances that situate individuals in relation to, in this case, quantitative literacy. This allows us to explore how teaching and learning performances may or may not be constrained by curriculum and other statements of policy. However, the application of an analytical framework similarly situates the *researcher* in relation to the quantitative literacy event and is thus also performative in nature. A meta-frame, we argue, allows one to critically engage with the framework as performance. This is necessary because the introduction of new artefacts changes the nature of the performances produced. As such, these artefacts, including frameworks and other human and non-human actors, are significant protagonists within the performance of teaching and learning (Riveros and Viczko, 2015). Contrary to the way they are often presented, frameworks and other such artefacts, are not mere 'tools' that simply and passively represent human endeavour; rather, they 'fix' human endeavour to particular points in time and space.

The implication of this is that the application of analytical frameworks for teaching and learning, or for assessment, or for curriculum design and development, is performative in nature, as has been shown to be the case with the framework applied herein, which is used within national benchmark testing in South Africa. Such frameworks exist in particular relation to lived teaching and learning experiences, and position teachers, learners, researchers and curriculum developers in particular ways. Frameworks thus fall short of speaking to teacher and learner experiences and we have argued that these need to be taken into account through the application of meta-frames. The meta-frame places teaching, learning and the framework in relation to each other and, we would argue, allows for constructive conversation around, for example, curriculum development. This is not an argument *against* frameworks; rather, it is an argument *for* consideration of how the application of frameworks (curricular, assessment, managerial, research) that predominate within institutions of higher education perform higher education in particular ways. The frameworks deployed within communities and institutions serve the purposes of those communities and institutions, but do not function outside of those communities. As such, it is important to consider what is excluded within such frameworks just as much as what is included.

Competing Interests

The authors have no competing interests to declare.

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