‘Looking at the workplace through ‘Mathematical Eyes” – work in progress

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In Ireland, the development of the ‘knowledge economy’ is a national priority predicated on a trained, adaptable and flexible workforce (NDP/CSF Information Office, 2007). More than ever, problem solving, spatial awareness, estimation, interpretation and communication skills, i.e. numeracy, are highly valued in the modern worker as being essential to support change, reaction and response. Many of these skills may be denied or dismissed as ‘just part of the job’, being inextricably bound up in work practice. In this way, skills deployed from a ‘common sense' perspective may tend to render mathematical ability invisible, rather than exposed and available for development. As an introduction to the research project, this paper considers a range of factors that may impinge on the adoption of a research methodology and development of instruments by which the mathematical knowledge, skills and competence (MKSC) underpinning a job may be identified. In addition, the National Framework of Qualifications in Ireland is explored for its capacity to make the uncovered MKSC more visible as to domain and sophistication, and to support communication amongst workers, employers and educators.

Introduction

Although planning is in its embryonic stage, the title of this research project suggests that observation of work in process, through a lens sensitised to mathematical content, may inform the extent to which work is underpinned by mathematical knowledge, skills and competence (MKSC). That these may be overlooked, denied or dismissed presents challenges for workers, employers, educators and those engaged in workplace research. While the term ‘workplace’ is in common use, it does not enjoy universal meaning. A range of internal and external forces may exert influences on people in workplaces, affecting their construction of a ‘job’ concept and development of workplace skills.

That the MKSC people use every day could be considered ‘just part of the job’ and to some extent invisible, poses problems in at least two dimensions. Firstly, according to the National Development Plan (NDP) in Ireland, a lack of appropriate MKSC can have a critical impact on a person’s continuing employability (NDP/CSF Information Office, 2007). Longitudinal studies, conducted in the United Kingdom, tend to confirm the correlation between low levels of numeracy and poor long term employment prospects (Bynner & Parsons, 1997; Bynner & Parsons, 2005). Furthermore, the Expert Group on Future Skills Needs in Ireland predicts that by the year 2020, only 7% of jobs will be accessible by those with lower secondary education alone (Expert group on Future Skills Needs, 2009).

Secondly, a failure to identify MKSC and the extent to which they exist, poses significant challenges for education and training programmes for want of a starting point, i.e. the so-called ‘bootstrap problem’ (Klinger, 2009).

In summary, this research seeks to investigate ‘invisible mathematics’ by developing ‘Mathematical Eyes’, through which wholly or partially hidden MKSCs can be perceived and modelled. Having been thus exposed, they can be traced to their origins and aligned with the National Framework of Qualifications (NFQ) in Ireland.

This novel approach to profiling mathematics in the workplace has the potential to position jobs, labour pool planning and development and learning provision in relation to the NFQ, and may constitute a step towards alignment with other frameworks.

The potential benefits accruing to individuals of being made aware of their ability with MKSC may include a review of their self perception as not being a maths person, and encouragement to pursue further development. Acknowledgement of their skills may support the Recognition of Prior Learning, and empower them in their work and elsewhere. They need no longer equate what they know with what they do, and instead become aware of their inter-sector mobility.

The employer, accurately informed by the MKSC requirement of existing, changing and planned jobs will be more likely to recruit suitable personnel. Providing learning and training opportunities, specific to the identified need could be more efficient use of time and money. Personnel matched to the requirements of their job, whose potential to develop is leveraged by the company, experience fulfilment and satisfaction, with a consequent positive effect on retention and absence.

Workplace learning and training providers may benefit from a clearer indication of the skills required by the company and, being equipped with an audience profile based on their work, can adjust their content and delivery methods accordingly.

Methodology

This paper preludes research that is planned to take place over a period of 3 years. It presents a review of the enfolding literature and a description of the National Framework of Qualifications (NFQ) with which some of the research findings will be benchmarked. It is recognised that research in the workplace is difficult, especially in an economic context in transition from unprecedented growth to catastrophic contraction and featuring rapidly rising levels of unemployment. The first author’s extensive workplace-experience suggests that a job's title is seldom a stable indicator of its component skills. It is common for a job to comprise procedures, mediated by technology, enmeshed in preceding and following activities, wrapped in a department and encapsulated by an organisation. There may exist several different yet concurrent perceptions of the nature, extent and content of a job, from the points of view of the management, worker and observer.

In this light, it is anticipated that special tools and instruments of enquiry will be needed to select a job and set its boundaries, by stripping away the successive layers that conceal it. Having set the context of the job, the research will proceed to identify the component skills and calibrate them for mathematics domain and sophistication. It is crucial that such instruments will collect qualitative and quantitative data in a manner that is amenable to analysis and sufficient to establish validity and reliability.

'Building Theory from Case Study Research' (BTCSR) as developed by Eisenhardt has been selected as the methodology most appropriate to meet the challenges posed by workplace research of this kind (Eisenhardt, 2002). While collecting substantial amounts of data concerning relatively few cases may be vulnerable to idiosyncratic interpretation, the richness of data may facilitate within and across case analysis. Furthermore, other frameworks that seek to report on skills that are considered to be essential in the workplace will test validity and provide a measure of triangulation.

This paper is concerned with developing an understanding of the problem space prompted by the following research questions:

1. What mathematical knowledge skills and competence (MKSC) underpin the different mathematical contextualisations in workplace settings?
2. What impact does MKSC invisibility have on the workplace?
3. How can the mathematics identified be best aligned in terms of knowledge skills and competence with the National Framework of Qualifications (NFQ)?

These questions imply that mathematics may be present in subtle ways particular to workplace contexts. Rather than being the overt application of mathematical techniques, elements of work may be supported and enabled by mathematics and find expression in the performance of routine. The continuous repetition of procedure may have far reaching affects on the development of the person and their readiness to adapt, innovate and create. Making the workplace MKSC more visible to the worker, employer and educator may support the individual in their own development and lifelong employability, enable the employer recruit more effectively and facilitate the design of learning provision.

This paper discusses the characterisation of mathematics that is addressed by this research and how mathematics might become invisible to 'everyday eyes'. A heightened awareness to partially or wholly concealed MKSC is depicted as observation through 'mathematical eyes' for its potential to detect otherwise invisible mathematics. The scope of the National Framework of Qualifications in Ireland, as a means of increasing the visibility of mathematics for the benefit of stakeholders is described, followed by a discussion of some of the challenges facing this research

Mathematics

Mathematics may be understood as an intellectual discipline, important for its own sake, for the knowledge economy, for science, technology and engineering, for the workplace and the individual citizen (Smith, 2004). In this context, mathematical skill is much sought after for its power to place logical and critical reasoning at the service of problem solving. It has been characterised as a field of study burdened with a series of dichotomies viz., fallibilist or absolutist, authoritarian and separated or humanist and connected, abstract or realistic, thus affecting the ways in which it is perceived by students and teachers (Ernest, 1995).

The term ‘mathematics’ can evoke recollections of school curricula and may be accompanied by negative feelings and anxiety, rooted deeply in early years education and persisting beyond the classroom (Klinger, 2009). However, real life and work situations are not neatly packaged and appropriately labelled as to the relevant mathematical discipline which will provide solutions. Instead, workers approach practical tasks with a broad range of skills, attitudes and knowledge including:

- Situational (vocational and other) knowledge and skills, (in particular, mathematical);
- Meta-cognitive skills and strategies (e.g. critical thinking, planning, problem solving and evaluating); and
- Personal skills (FitzSimons, 2002).

‘Mathematics’ and ‘Numeracy’ are sometimes used in the literature to describe the same field of study (FitzSimons, Jungwirth, Maasz, & Schloeglmann, 1997). The latter has been differentiated from the classroom discipline and come to refer to the range of mathematical knowledge and skills that adults use in managing situations in their everyday lives (NALA, 2004). Numeracy involves cultural, social and emotional facets (Maguire & O'Donoghue, 2003), and enables effective participation, albeit bounded by context (Evans, 2000). In a dynamic world, mathematical habit of mind i.e. discussing, sharing, challenging and reflecting support the individual in responding to change (Hoyles, 2008).

For some, the range of skills and knowledge required to assimilate, analyse, and react to changing demands of a society saturated with quantitative information and technology is referred to as numeracy (van Groensteijn, 2002). Common mathematical themes encompassed by numeracy derive from van Groensteijn’s proposal in 2002, later refined by Maguire as including Quantity and Number, Space and Shape, Pattern and Relationship, Data handling and Chance, and Problem Solving (Maguire, 2004).

Detecting the deployment of mathematical skills in workplaces necessarily involves the observation of people’s behaviour as they engage in work processes. Of particular interest in this project is numerate behaviour characterised as employing a range of problem solving skills, and involving situation management:

> Numerate behaviour is observed when people manage a situation or solve a problem in a real context; it involves responding to information about mathematical ideas that may be represented in a range of ways; it requires the activation of a range of enabling knowledge, factors, and processes (Gal, van Groensteijn, Manly, Schmitt, & Tout, 2003).

Such concepts as mathematics and numeracy, being multifaceted, are understood by different people in different ways. The logical consequence is that some, if not all, of the MKSC that underpin the strategies used to manage everyday life situations are rendered invisible to the people who use them.

Invisible Mathematics

How does MKSC become invisible? There may be several factors that interact with aspects of the workplace in various degrees and combinations that may be unique to the individual, which contribute to making invisible to some extent the set of MKSC they deploy in work.

Invisible Mathematics – possible affecters

The widespread public image of mathematics is suggested by Ernest to be negative, remote and alien to their personal and professional concerns and their self-reported abilities (Ernest, 1995). The self-image of 'not being a maths person' leads to the assumption that the work such a person does cannot involve mathematics, because if it did, they could not do it. The MKSC actually used is thought of as 'all part of the job' or common sense – anything but mathematics (Coben, 2000), thus rendering mathematics content irrelevant and invisible.

Such situations have been termed 'the relevance paradox i.e. where the social significance of mathematics co-exists with its subjective irrelevance and invisibility (Wedege & Evans, 2006; Niss, 1994). Workers often fail to recognise or credit themselves with the mathematics involved in work they are doing, denying it to researchers or dismissing it as common sense (Harris, 1991). Previous research suggests that the proliferation of technology in the workplace has the effect of embedding MKSC in routines and artefacts designed by others, tacitly learned, and frequently intertwined with associated procedures (Hoyles, Wolf, Molyneux-Hodgson, & Kent, 2002). In this way, concealing the MKSC content of work may construct and reinforce a discontinuity between school understanding of mathematics and that which underpins workplace activity.

So-called 'invisible mathematics' is associated with ethnomathematics (D'Ambrosio, 1985) and is considered to have several negative affordances. The embedding of mathematics in a particular context tends to confine the skills learned, causing mathematics to be always 'out of reach'. It compounds a person's lack of confidence in their numerate abilities and the perception that mathematics appears as formulae or algorithms. Ideas of there being only one answer and that it tests powers of recall rather than the potential to investigate evoke school experience and become the received wisdom throughout society. The mathematics skills that adults use outside school are not contiguous with their school mathematics and are thus fragmented and difficult to transfer (Coben, 2000).

Research suggests that the employer, not being accurately informed of the numeracy skills required by the job description, compounds invisibility. These perceptions are often normative, insofar as they reflect value judgements rather than demonstrable fact (Marsick, 1997; Hoyles et al., 2002). Modern employers value in their employees a command of multiple methods of problem-solving rather than a finite range of algorithms suggested by formal school mathematics (Hudson, 2008).

While the workplace influences the skills deployed and how they are experienced by the worker, other subjective affecters can have a significant impact on the person's appreciation of their own MKSC. For example, reflecting on *The Framework of Numeracy Concept Sophistication* indicates that some mathematical concepts may be unknown and invisible to the individual whose numeracy development is located in the formative stage (Maguire & O'Donoghue, 2003).

Perceptions of oneself as a learner of mathematics, bundled in with difficulty, dislike and negative memories of the classroom, contribute to feelings of anxiety about mathematics (Reyes, 1984 in Evans, 2000). Mathematics may have been experienced as useless and even inappropriate when compared to the student's real world or ambitions. It may be a condition learned from siblings or class colleagues i.e. more behavioural than cognitive (Hembree, 1990). A deep seated belief of mathematics being anathema to the person may reinforce the common-sense view that the skills they deploy cannot be underpinned by mathematics, because they 'don't do mathematics'.

Similarly, community and cultural factors, e.g. the belief that mathematics is a male domain (Chipman & Wilson, 1985), will deter girls. The concept of '*habitus*', in the sense of patterns of thought and behaviour internalised from surrounding culture, social structure and experience, also impinges, not least because of its durability (Bourdieu, 1977) and its power to excuse a lack of MKSC. Attitudes developed from a bad experience with mathematics can persist over many years, permitting negative attitudes to project across generations, compounding the 'denial' of mathematics ability in oneself (Benn & Burton, 1993). It has been asserted that a negative self-image in relation to mathematical ability promotes a common sense explanation for any mathematical activity displayed (Marr & Hagston, 2007).

How can common sense help the individual reconcile the MKSC content in their work with their self perception of having neither use nor aptitude for MKSC?

Common sense

Common sense is reported to be an innate, naturally occurring human characteristic which is motivated by the desire to behave intelligently. It is developed and maintained by a cyclical guide to action viz. experience, analyse, decide, and execute (Colleran, O'Donoghue, & Murphy, 2003). It seems that the opportunity to reflect is deferred until a similar experience arises in the future, at which time previous actions are reviewed for relevance and selection as a decision support. It has been further described as a collection of insights, accumulated by a community (or individuals within it) in a socio-historic setting. The same event may be experienced differently by different individuals and assimilated into an ever growing fund of workable solutions to their everyday tasks. Being motivated by purpose, it clings to the immediate, practical, concrete and particular. The cultural context in which common sense is expressed, determines the conditions under which humans can interact to produce intelligent actions and outcomes (Colleran et al., 2003).

Because common sense is practical, natural and thin, it is thought to explain why mathematical skills are easily absorbed and concealed by it. It is practical in the sense that it guides intelligent behaviour. It occurs naturally, though not in predictable proportions and is never finished. Its being thin refers to its amenability to reason, thus helping to place it 'beyond question, as a matter of faith and bolstering its resilience' (Geertz, 1993).

Geertz further suggests that common sense is a *potpourri* of disparate notions applied *ad hoc* and therefore is in sharp contrast with the rigorous application of mathematical methods. This assertion is challenged by Lonergan's Spontaneous Commonsense Cognitional Structure (Lonergan, 1957), adapted by Colleran, which illustrates the operation of common sense. The idea that '… common sense is something to be transcended rather than rejected' (Gramsci, 1971), inspired Coben to recognise the power of lived experience as an educative process that could be harnessed by adults learning mathematics (Coben, 2000).

According to Cockroft (Cockcroft, 1982) mathematical tasks, performed using the tools at hand (in the workplace) become part of common sense through frequent repetition. It seems that common sense is a crucial life skill, developed cumulatively over time, by direct and vicarious experience, in multiple social and cultural settings, and supported by formal and informal instruction. It is plastic and malleable, is used unconsciously, and without apparent concern for the genus of the skills employed. It is a matrix of seamlessly interrelated resources that, being accessed as a whole, renders its constituent parts including MKSC invisible.

Thus being aware of 'invisible mathematics', the project will develop and adapt 'Mathematical Eyes' observation tools, capable of detecting the extent and calibre of MKSC displayed in selected workplaces.

Mathematical Eyes

The concept of 'Mathematical Eyes', inspired by Amy Benedicty (Benedicty & Donahoe, 1997) and developed by Maguire (Maguire, 2003), encapsulates the sense that humankind experiences the 'real' world everyday, which incorporates many mathematical themes. Rather than being a separate, isolated, absolutist (Ernest, 1995), classroom-bound phenomenon, the many facets of mathematics are inextricably bound up with the real world and become visible once the eyes with which to see them have been developed.

Just as human vision perceives only a narrow spectrum of light, so too will many overlook the mathematical concepts that pervade everyday work and life when they see things through what might be called 'Everyday Eyes'. In addition to quantity and number, 'Mathematical Eyes' perceive problem solving, space and shape, pattern and relationship, data handling and chance. In contrast, viewing the workplace through 'Everyday Eyes' gives prominence to the internal and external affecters, occluding the underlying the MKSC, as shown in Fig. 2.[1]

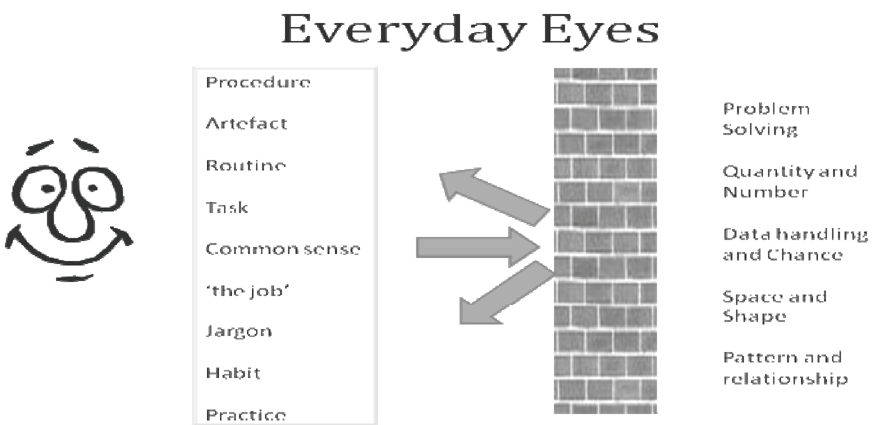

Fig. 2 Looking at the workplace through 'Everyday Eyes'.

[1] Figure 2 is a visualisation of how the repetitive nature of work - being framed by procedures, mediated by artefacts, reinforced by training, jargon and other factors - develops habits which tends to suppress the underlying MKSC.

In contrast, looking at the workplace through 'Mathematical Eyes' (Figure 3[2]) helps to identify the mathematical knowledge and skills that underpin the performance of work.

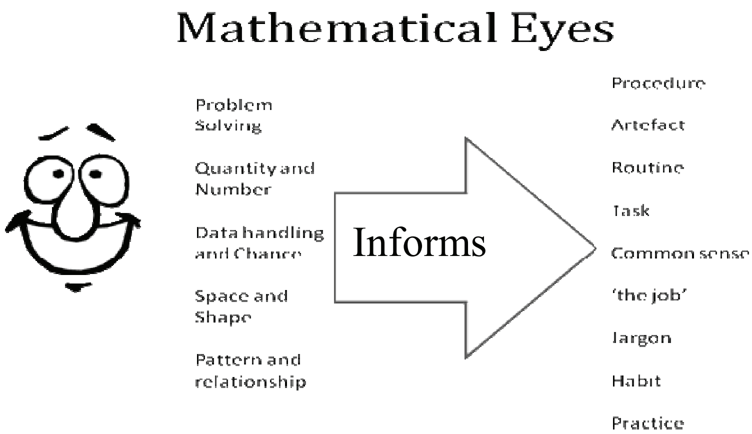

Fig. 3 Looking at the Workplace through 'Mathematical Eyes'.

Revealing heretofore hidden knowledge, skills and competence, and the extent to which they are made real, presents an opportunity to enhance understanding and inform the scaffold upon which future learning can be developed for the benefit of workers and work-based education providers (Brown, Collins, & Duguid, 1989). Developing Mathematical Eyes as an observation tool is a fundamental component of this research for detecting and gathering information. Making the findings more visible however, requires the support of a framework that is sensitive to the degree, diversity and complexity of learning outcomes to which it attests. Such a framework, entitled the National Framework of Qualifications (NFQ), was developed by the National Qualifications Authority in Ireland and launched in 2003.

The National Framework of Qualifications (NFQ)

The National Qualifications Authority of Ireland (NQAI, 2003), was set up in 2001 to establish and maintain the National Framework of Qualifications , in order to recognise and award qualifications based on standards of knowledge, skill and competence acquired by learners. Its structure offers a new metric for achievement in more breadth and depth, across all subject areas.

The NFQ provides for 10 levels of achievement, from the Elementary or Foundation Level 1, rising incrementally through to Levels 4 and 5, equivalent to the completion of upper- secondary school leavers. This is followed by Level 6 indicating a post upper-second level award often provided as a precursor to University. Levels 7 through to 10 attest to Bachelor degrees at ordinary and honours standards, Masters Degrees and Doctorates respectively. Every level of achievement may be classified in 3 main strands, each refined by attendant sub-strands as follows:

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[2] Figure 3 Giving prominence to the underpinning MKSC allows work practice to become an expression of the mathematics concepts which lie at the foundation of adaption, innovation and creativity.

Knowledge: Kind and Breadth, Skills: Range and Selectivity, and **Competence**: Context, Role, Learning to Learn and Insight. Differentiation between levels is guided by textual specification which may be vulnerable to idiosyncratic interpretation (NQAI, 2003).

Knowledge: Kind and Breadth
Knowledge-***Kind*** refers to its nature and quality, and the manner in which it accumulates. The ability to make sense of new knowledge, contrasting it with, and drawing on, pre-existing knowledge, indicates progressively higher levels of learning.

Knowledge-***Breadth*** levels reflect degrees of complexity, specialisation and diversity rather than volume. Breadth of knowledge is thought to develop along a continuum from the elementary at level 1, specialised at level 5 and considered to be in the forefront of a particular field of study at level 10.

Know-how and Skill
Know-how refers to the procedural knowledge required to carry out a skill i.e. the performance of a task, directed towards a goal. The know-how that underpins skill, may be inferred from its performance, and may be dependent on declarative knowledge while it is being acquired.

Skill-***Range*** levels reflect the skills to use tools ranging from the commonplace to the novel, in addition to the diversity and degree of completeness of the skills appropriate to an area of activity.

Skill-***Selectivity*** is a measure of a persons' ability to assess the skills demands of a task arising in their environment and to judge whether it is within their capabilities. Selecting and applying the appropriate tool from a range of possibilities, is an index of the workers' understanding of their environment and appraisal of the requirements of the task.

Competence – National Framework of Qualifications
The major strand of Competence addresses the application of acquired knowledge and skill in human situations, whether social, civic or occupational. It concerns attitudes, beliefs, emotions, values and a sense of self efficacy. Rather than overtly taught and learned, it is a measure of personal and professional development, woven into course content and typically acquired by practice, feedback and reflection.

The NFQ addresses the notion of Competence in four different dimensions viz., ***Context, Role, Learning to learn*** and ***Insight***.

The ***Contexts*** in which knowledge and skills may be applied are constructed by humans and may range from the simple and very structured at one end of the spectrum to the highly complex and unpredictable at the other. There is research suggesting that many jobs consist of quite basic mathematics being deployed in complex situations, or that much complex reasoning is required before the application of basic mathematical operations, exemplifying low levels of knowledge being deployed in ways that indicate high levels of competence (Wadsworth, 1997; Wake, 2005).

The variety of ***Roles*** occupied by a worker may range from the simple, highly defined and supervised, requiring lower levels of learning, to the diverse, volatile and unpredictable, requiring the application of social and leadership skills associated with higher levels of learning. Here too, more advanced and perhaps multiple roles may be taken on by a person with elementary levels of knowledge, as evidenced by the ability to adopt the appropriate role on joining a group whether simple or diverse.

The levels of competence linked to ***Insight*** imply a scale of understanding and consciousness developed by reflecting on experience and feedback from the general environment. The ability to integrate other learning outcomes with one's set of attitudes, motivations and beliefs, enhances self understanding and promotes increasing levels of autonomy in interaction with society.

Learning to learn is being able to recognise one's limitations and taking the appropriate measures to transcend them. To observe and participate in new experiences and, by reflection, extract and retain new meaning from them while drawing on other strands of knowledge and skill, underscores the relationship between learners and their learning processes.

Aligning MKSC to NFQ

It is clear from the above that the capacity of the NFQ is sufficient to measure many aspects of achievement, reaching beyond degrees of difficulty or a simple pass/fail test. Learning from a strategy to impose order on mathematics for the benefit of NCVA (O'Donoghue, 2000), this project seeks to untangle mathematical knowledge and skill content from overall job performance. Observing the job in progress through 'Mathematical Eyes' will expose space and shape, quantity and number, data handling and chance, pattern and relationship and problem solving skills in action. The NFQ provides extensive scope within which to classify the texture of knowledge and skills and the subtleties of the extent to which they are deployed.

This research anticipates that jobs will differ in the combination of mathematical skills deployed and the attendant level of sophistication. It is possible that fairly rudimentary operations may be applied only as a final step in a sequence of complex synthesis and analysis of information gathered from a variety of sources. However, this is not to underestimate the challenge of profiling the contextualisations of mathematics encountered in the workplace, nor the development of a reliable model with which to map them onto the NFQ.

Discussion

'Looking at the Workplace through Mathematical Eyes' is a research project in development. A wide ranging trawl of existing research has set out the relevance perimeter of the enfolding literature and has helped develop the researcher's understanding of the problem space. The authors consider that a continuing literature review will have a grounding effect throughout the life of the project.

The workplace is a challenging environment. It is difficult to make meaning of the multiple ways in which inherently simple elements may be organised to achieve a goal without first establishing the context of the work being observed. Work processes may vary in order to respond to conditions imposed by the customer, product or cyclical schedule. Individuals may have the same responsibilities, and belong to the same work group, yet adapt their work to their personal preferences. A job may comprise components which, in isolation from the whole, may lack coherence and meaning for the worker, promoting the habits of activity rather than the 'habits of mind' (Hoyles 2008).

Following a Pilot Study, this research will shadow relatively few jobs in different organisations. A number of instruments, currently under development, will serve to orientate the researcher in the overall context of the company and in setting boundaries to a selected job. The mathematics content of the job will be detected by observation through 'Mathematical Eyes' and calibrated as to domain and sophistication. These findings will be made visible by reference to the provisions of the NFQ to promote communication between the stakeholders and make a contribution to the recognition of prior learning acquired by informal and non-formal means.

A heightened awareness of the role of mathematics in everyday work situations may promote their development as powerful agents of innovation and creativity. Designers of pedagogical content may be inspired by more visible examples of MKSC in the workplace for the benefit of learners. Employers, being more conscious of the job requirements, may be supported in their recruitment and training provision. Finally, individuals may be empowered to embrace change in the form of new expressions of their MKSC a instead of continually replacing old habits with new patterns of activity.

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