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Why Is Improvement Difficult?

Garrod Lecture 2015

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Abstract (250 words)

The pressing need to measure and improve antibiotic use was recognised over 40 years ago, so why have we failed to achieve sustained improvement at scale? In his 2014 Reith Lectures about the future of medicine the US surgeon Atul Gawande said that failure in medicine is largely due to ineptitude (failure to use existing knowledge) rather than ignorance (lack of knowledge). Consequently it is notable that most Interventions to improve antimicrobial prescribing are either designed to educate individual practitioners or patients about policies or to restrict prescribing to make practitioners follow policies. Interventions that enable practitioners to apply existing knowledge through decision support, feedback and action planning are relatively uncommon. There is an urgent need to improve the design and reporting of interventions to change behaviour. However, achieving sustained improvement at scale will also require more profound understanding of the role of context. What makes contexts receptive to change and what elements of context, under what circumstances, are important for human performance? Answering these questions will require inter-disciplinary work with social scientists to integrate complementary approaches from Human Factors and Ergonomics, Improvement Science and Educational Research. We need to rethink professional education to embrace complexity and enable teams to learn in practice.

Workplace based learning of improvement science will enable students and Early Career Professionals to become change agents and transform training from a burden on clinical teams into a driver for improvement. This will make better use of existing resources, which is the key to sustainability at scale.

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Introduction

The UK 5 Year Antimicrobial Resistance Strategy 2013-2018 recognises the importance of reducing inappropriate antibiotic prescribing,[1] the implication being that antibiotic resistance is largely a consequence of the selective pressures of antibiotic usage and that reducing these pressures by the judicious administration of antibiotics will facilitate a return of susceptible bacteria or, at least, will prevent or slow the pace of the emergence of resistant strains. At the same time, sepsis kills more people annually in the UK than myocardial infarction or breast, colon and lung cancer combined and delay in effective antibiotic treatment is associated with increased mortality.[2-4] The term antibiotic stewardship is used to capture the twin aims of ensuring effective treatment of patients with infection and minimising collateral damage from antimicrobial use. [5]

The pressing need for antimicrobial stewardship was actually well recognised over 40 years ago[6] and clear plans for measurement and improvement of antibiotic use followed soon after on both sides of the Atlantic.[7, 8] By the 1990s failure of these initiatives led to worldwide demands for concerted action to limit the development of antibiotic resistance through improvement in the use of antimicrobials.[9-13] So why have we failed to achieve sustained improvement at scale? In his 2014 BBC Reith Lectures series The Future of Medicine the American surgeon Atul Gawande examined the nature of progress and failure in medicine.[14] He argued that failure in medicine is largely due to ineptitude (failure to use existing knowledge) rather than ignorance (lack of knowledge) and that progress will only be achieved through systems that are better designed to transform care from the richest parts of the world to the poorest. In The Century of the System" Gawande said that in the 20th Century "we were fooled by penicillin" into thinking that medical progress would come simply from the discovery of new molecules. The misguided quest for simple solutions to complex problems is also seen in attempts to improve healthcare, which Gawande described as either primitive (writing guidelines to tell people what to do) or mediaeval (issuing targets with rewards and penalties to make people follow the guidelines).

In this paper I reflect on how we can use systems thinking to achieve sustainable improvement in antimicrobial stewardship at scale. I will focus on the evidence base for improving antibiotic prescribing for hospital inpatients[15, 16] but the same issues apply to prescribing in primary care. We need to look beyond antimicrobial prescribing to evidence from the social sciences about how to change behaviour,[17] improve systems[18] and apply the findings of educational research to learning in practice.[19]

Evidence About Improvement

Design and Reporting of Interventions to Improve Hospital Antibiotic Prescribing

The Cochrane systematic review of interventions to improve antibiotic prescribing to hospital inpatients identified 89 studies published up to end of 2006, which showed that a variety of interventions can change hospital antibiotic prescribing.[15] However, there are still important gaps in the evidence about antibiotic stewardship from the previous systematic review in four key areas.[16]

1. Extraction of more detail about behaviour change techniques by application of control theory to the synthesis of evidence.[20, 21]
2. Reducing patients' exposure to antibiotics by targeting the decision to treat or the duration of treatment rather than simply targeting the choice of antibiotic, dose or route of administration.
3. Balancing measures of unintended consequences, which should be an integral component of any quality improvement intervention.[22, 23]
4. The evidence about the impact of interventions on microbial outcomes is relatively weak because only 12 (13%) of studies included robust data about both prescribing and microbial outcomes.

In the update to the review[16] we are applying the Behaviour Change Technique (BCT) Taxonomy v1, which is an extensive, consensually agreed hierarchically structured taxonomy of techniques [behavior change techniques (BCTs)] used in behavior change interventions.[24] In addition we are applying a recently published checklist for intervention reporting [25] and the editorial policy on describing the content of complex behaviour change interventions from the journal Implementation Science.[26] Our review will include literature published up to the end of December 2014 but we decided to publish preliminary findings from studies published up to the end of December 2012 in order to improve the awareness and reporting of BCTs in antimicrobial stewardship interventions.[17] There is a strong evidence base from a wide variety of contexts about the effectiveness of the BCTs of goal setting, self-monitoring, feedback and action planning.[17] We identified 116 studies reporting 123 interventions. Reporting of BCTs was poor, with little detail of BCT characteristics. Goals were reported for all interventions but poorly specified (Figure 1a). Most interventions provided participants with some instruction on how to achieve the goal but nearly half (44%) did not specify higher order goals (i.e. did not explicitly link improvement in process with important clinical, financial or microbial outcomes) and only 9% involved the participants in setting targets (Figure 1a). Although 9% of interventions specified a goal threshold and 4% set a time by which the goal should be achieved (Figure 1a), only one of the 123 interventions specified both goal threshold and timescale. Feedback was reported for 18 (14%) of interventions, action planning and self-monitoring were only used in one intervention (Figure 1b). The literature we reviewed included just one example of a hospital stewardship intervention that included all of the evidence-based BCTs.[27] The failure to include participants in goal setting, measures for improvement or action planning means that the design of most published interventions has not been informed by identification of reasons for failure to meet standards, which was identified as an important missing link in the audit cycle over 20 years ago (Figure 2):

> *"Although many audit studies describe deficiencies in health care, few identify the underlying causes. In consequence, the strategies for change which are developed may not address the fundamental problems. An important link in the audit cycle is missing, and failure to include this step is hampering the success of audit."*[28]

Unfortunately our review shows that the majority of antimicrobial stewardship interventions still do not consider why prescribers do what they do as opposed to what the guidelines say. They are assuming that failure to follow the guidelines is due to ignorance, whereas failures in medicine are rarely due solely to lack of knowledge and almost always involve barriers to doing the right thing.[14] Consequently interventions should include components that increase enablement to implement evidence-based practice, defined as "increasing means or reducing barriers to increase capability or opportunity".[29]

BCTs that enhance enablement include self-measurement, feedback and action planning.[29] The design of stewardship interventions should adopt practical guides to sustainable measurement by clinical teams (Figure 3

) and readily available online resources that support the design of goal setting, measures for improvement and feedback [30, 31].

The Importance of Action Planning and Actionable Feedback

The low frequency of action planning in antimicrobial interventions contrasts with other areas which have demonstrated the success of providing goal-setting, feedback and action planning in changing health professional behaviours.[17] Reducing Antibiotic Prescribing in Dentistry (RAPiD) is a recent clinical trial that provides an example of successful use of action planning to enhance audit and feedback about antibiotic use at scale.[32] The RAPiD trial recruited 795 Dental Practices and randomised them into three groups: control (n=163), Audit & Feedback Intervention (n=316) and Audit & Feedback plus TRIaDS BC Intervention. The TRIaDS (Translational Research in a Dental Setting) BC (Behaviour Change) text-based intervention was based on the sections on bacterial infections, in the published SDCEP (Scottish Dental Clinical Effectiveness Programme) clinical guidance on 'Drug Prescribing for Dentistry'[33] These were coded for the presence/absence of BCTs using the BCT taxonomy (Table 1).[24] Two BCTs were identified: instruction on how to perform the behaviour (Sub-Goal specification); and provide information about health consequences of performing the behaviour (Higher Order goal specification). These BCTs were therefore selected for inclusion within a text-based intervention (Table 1). The SDCEP guidance included behavioural instruction relating to pre-decision processes, *i.e.*, whether or not it is appropriate to prescribe antibiotics; and post-decision processes, *i.e.*, ways to optimise antibiotic prescribing once the decision to prescribe had been made. The Text Intervention only included the BCTs that focussed on the pre-decision processes. Where possible, the exact wording from the SDCEP guidance document was used but some recommendations were combined to shorten the text (Table 1). A number of potential BCTs coded in the guidance had to be excluded from the final text-based intervention due to insufficient specification of behaviour. For example, the behaviour 'take care' within 'take care when prescribing these antibiotics to vulnerable groups' was not explicit enough to be included as 'instruction on how to perform the behaviour'. Note that the instruction *"'This should be the first step even if patients request antibiotics and even when time is short"* was added to the guideline recommendation to use local measures first following consultation with Dentists. Antibiotic prescribing in the intervention groups was 6% lower than in the control group. In addition antibiotic prescribing was 6% lower (p=0.005) for groups receiving the Behaviour Change (BC) intervention *vs* groups receiving Audit & Feedback without any written BC intervention.

The RAPiD trial shows that evidence-based goal setting can be used to enable effective action planning at scale to reduce unnecessary antibiotic prescribing in primary care. A study of the development of an antimicrobial stewardship intervention in a neonatal ICU (NICU) showed that It may be more challenging to design actionable feedback in some hospital settings (Table 2).[34-36] The NICU staff were opposed to individualised feedback on the grounds that it was hard to assign individual responsibility for specific antimicrobial usage and they also had major concerns about the implications of any feedback on peer or supervisor judgement (Table 2). The challenges around customised feedback centred on convincing NICU staff that national policies applied to their patients (Table 2). Similar issues were encountered in a UK study of determinants of antimicrobial prescribing in two hospitals, which showed that perceived threats to decision making autonomy and limitations of local evidence-based policies were also encountered in interviews with a wide range of staff.[37] Etiquette (reluctance to be seen to criticise others) was a cross cutting theme that was embedded within each of the other three themes (Table 3) and also probably contributed to the challenges encountered in a NICU in the USA (Table 2).

Patel et al[36] believed that they had partially solved the challenge of timeliness by feeding back data via two monthly meetings on the NICU supplemented with emails to staff before the meeting. However, monthly, email feedback about time to first antibiotic dose had no effect in an intervention designed to improve the management of sepsis on medical, general surgical and orthopaedic continuing care wards in a UK hospital.[38] It was challenging to engage with senior clinicians across multiple clinical units and teams.[38] The results of this study informed the design of the measurement plan for a national Sepsis Collaborative in Scotland, in which clinical teams identify patients with sepsis and use data collection sheets that include reminders about the actions to take for patients with suspected sepsis, severe sepsis or septic shock.[39] This approach promotes discussion about management of individual patients within clinical teams and so has the capacity to address cultural challenges as well as enabling data collection.

In conclusion, the challenges to actionable feedback on antimicrobial prescribing to hospital inpatients are most likely to be overcome by involving clinical teams in the collection of data in ways that also remind them about actions they need to take to improve care. There is limited research evidence about the issue of effective forms of safety feedback in healthcare compared with other high risk industries. We need to draw on the valuable operational knowledge that exists within diverse safety management communities. This shows that the design of effective feedback systems depends on leadership, the credibility and content of information, effective dissemination channels, the capacity for rapid action, and the need for feedback at all levels of the organisation.[40] Involving clinical teams in data collection is feasible (Figure 3) and actionable feedback can be achieved through review of individual cases.[41]

What explains variation in effectiveness of improvement interventions?

An example of a successful improvement intervention at scale is the Michigan ICU Project. This was associated with significant reduction in central line associated blood stream infections in 103 participating ICUs from 7.7 per 1000 catheter days to 1.4 at 16 to 18 months of follow up.[42] This successful intervention was delivered through checklists, which reminded participants about the care processes that needed to be implemented. In the UK the Matching Michigan study applied the same checklist in 215 ICUs. Over the study period there was a steady reduction from 3.7 at baseline to 1.5 central venous catheter blood stream infections per 100 catheter days but the reducation began in the pre-intervention period. The implementation of the checklist was not associated with any acceleration in the decline of infections. A possible explanation for these contrasting results is provided by detailed ethnographic evaluations of both the original Michigan ICU study[43] and the UK Matching Michigan study.[44] The results showed that the way the checklist was implemented in the Michican ICUs was best understood as a culture change intervention that made patient safety a priority. The checklist was simply the mode of delivery, the mechanism of change was the way that the checklist was used to promote discussion and teamworking.[45] Consequently there was no guarantee that adopting the same checklists would achieve the same culture change in other ICUs.[43] In the UK the Matching Michigan intervention was actually associated with reduction in central line blood stream infections in a minority of ICUs and the ethnographic research identified marked differences between these ICUs *versus* the majority where the intervention had no effect.[44, 46]The interventions in the successful ICUs were characterised by embedding data collection into the daily routine of the clinical teams with data sheets that reminded participants about important care processes as well as by regular feedback and discussion of results. In contrast the interventions in the unsuccessful ICUs were characterised by collection of information and decisions about infections by people who were not members of the clinical teams responsible for delivery of the intervention.[44, 46]

The insights from the Michiigan and Matching Michigan ICU studies[43, 44, 46] can be used to explain contrasting results of two studies that apparently used the same intervention to improve antimicrobial prophylaxis for elective surgery. The Trial to Reduce Antibiotic Prophylaxis Errors (TRAPE) randomised 22 participating hospitals in the USA to receive performance feedback alone

(Control) or to join an mprovement collaborative in addition to receiving feedback (Intevention). The results were similar to the Matching Michigan study[47] in that the outcomes improved signiificantly in all participating hospitals but there was no evidence that the intervention had any additional effect.[48] The authors concluded that "*the trial did not demonstrate a benefit of participation in a quality improvement collaborative over performance feedback for improvement of these measures."*[48] These results contrast with the success of an improvement collaborative to reduce unnecessarily prologned atimicrobial prophylaxis for coronary artery bypass graft (CABG) surgery in Taiwan.[49] The design for this intervention was based on detailed analysis of a previous improvement collaborative in orthopaedic surgery and included organising a team with senior leadership (hospital superinendent), middle management (administration, financial), system leader (chairman of Department) and clinical staff alongside a day to day project leader. The team reviewed the evidence to support improvement targets and the workflow for administration of prophylaxis in CABG. Measures for improvement were agreed and fed back to clinical teams. Whenever improvement in outcomes occurred it was standardised by consolidation of work processes and the division of cardiac surgery was complimented in public for the improvement.[49] In contrast The staff involved in the improvement collaborative in TRAPE were "physicians and nurses involved in infection control" and the authors note that "surgical staff or hospital leadership may have been insufficiently involved." [48] The failure of the improvement collaborative in TRAPE is almost certainly due to the fact that the investigators appeared to be unaware of key research about understanding the variation in success of improvement collaboratives in other contexts, which shows that a key difference between successful *versus* unsuccessful collaboratives is the ability to influence the political cultural or leadership context.[50] In contrast with the US TRAPE study[48], the successful Taiwan improvement collaborative explicitly recognised the need to address the political, cultural and leadership context in the participating hospitals.[49]

Implementing an intervention without asking why professionals currently do what they do and how the intervention might help them to change is an example of what Mary Dixon Woods has called "cargo cult quality improvement".[51] Cargo cult science was first described by the physicist Richard Feynman. Cargo Cults occurred on remote islands in the South Seas at the end of the 2nd World War. The reason was that aeroplanes had been delivering supplies throughout the war but then they stopeed coming. In order to make the aeroplanes come again the islanders made runways, built aeroplanes, control towers and air traffic control equipment out of wood and waited for the aeroplanes to land. They were baffled when nothing happened *The form is perfect. It looks exactly the way it looked before. But it doesn't work. No airplanes land. So I call these things Cargo Cult Science, because they follow all the apparent precepts and forms of scientific investigation, but they're missing something essential, because the planes don't land."*[52]

The aeroplanes delivered the supplies but the key question was why did they arrive? The answer was the urgent but temporary need for the USA to get supplies to remote islands that were previously of no strategic importance.

In summary, antimicrobial stewardship interventions have two major problems arising from failure to apply evidence from the social sciences. The first problem is not including effective behaviour change techniques in the design and reporting of interventions.[17] The second problem is failure to use theory to consider why and how an intervention like a checklist or an improvement collaborative might work in a particular context.[46] The first problem is relatively easy to fix but the second problem will require much more profound, interdisciplinary engagement with the social sciences.

Beyond Behaviour Change Techniques: Context, Systems Thinking and Educational Research

The Importance of Context

Research on variation in the rate and pace of change in the health sector and other industries has led to a key distinction between receptive *versus* non-receptive contexts.[53] A relevant example is the analysis of variation in the effectiveness of the UK Orthopaedic improvement collaborative (Figure

4).[50] Although some variation was explained by the details of how the collaborative method was adapted and how the improvement plan was implemented locally, context was the key explanatory factor. Moreover the influence of contex could be clearly separated into leadership, politics and culture (Figure 4).

Listing the factors that lead to receptive contexts for change is a necessary staring point (Figure 4) but it is *"the dynamic and ongoing interaction between these factors, rather than any one of them individually or independently, that accounts for the effectiveness of QI intervention and the striking variation between similar QI interventions in different places."*[50] Moreover differences in context within organisations can be greater than differences between organisations. A clear example is provided by research with junior doctors in the first two years after qualification in two UK hospitals. This showed extreme intra-hospital variation (Medicine was a completely different environment from Surgery in Hospital A and in Hospital B with very little inter-hospital variation (Medicine in Hospital A was similar to Medicine in Hospital B):[54]

> *"Our job really was to manage the more medical side of things and his job was the surgeon. … Umm, umm and it's not it's not like that at all in the medical side of the hospital it's purely in surgery and like the registrar who was almost a consultant some of them are fantastic but I think probably half of them are, expect their FY staff to deal with things like prescribing antibiotics and that kind of thing so they don't really keep up-to-date with it erm and because they are so much more of a surgeon than trying to treat things with medications they seem to be a bit out of touch*." Female F2, Location 1.[54]

The components of context listed in Figure 4 are all examples of 'inner' context, which is the intra-organisational leadership, politics and culture. It is equally important to consider the 'outer' context, for example the health system and broader social, economic or political trends and events.[50] `A helpful account of inner and outer context is provided in a review of the literature about implementation of new evidence in healthcare:[55]

"Changes in the outer setting can influence implementation, often mediated through changes in the inner setting. Generally, the outer setting includes the economic, political, and social context within which an organization resides, and the inner setting includes features of structural, political, and cultural contexts through which the implementation process will proceed. However, the line between inner and outer setting is not always clear and the interface is dynamic and sometimes precarious. The specific factors considered 'in' or 'out' will depend on the context of the implementation effort. For example, outlying clinics may be part of the outer setting in one study, but part of the inner setting in another study. The inner setting may be composed of tightly or loosely coupled entities (eg, a loosely affiliated medical centre and outlying contracted clinics or tightly integrated service lines within a health system); tangible and intangible manifestation of structural characteristics, networks and communications, culture, climate, and readiness all interrelate and influence implementation."

Antibiotic prescribing in hospitals involves multiple team members who are reluctant to change decisions made by others, particularly if they are more senior. To influence the antimicrobial prescribing of individual healthcare professionals, interventions need to understand prescribing etiquette and power relations by using clinical leadership within teams to influence practice.[37] Junior doctors make complicated antibiotic prescribing decisions in challenging contexts. Research in two UK hospitals identified two key problems: first conflicting advice given by senior staff and second a dearth of supervision or feedback.[54] The research team's solutions to these problems included two interventions that applied the concepts of action planning and feedback. The first solution encouraged the explicit sharing of decision-making steps, so that junior doctors could see the rationales underpinning the prescribing decisions made by their seniors and discuss how they could apply these to their own decision making. The second solution was to provide junior doctors with a new model of support and feedback to provide them with the autonomy to work independently, whilst accessing support and receiving feedback regularly and when most needed.

In summary, context is a slippery subject because of the constant, dynamic interactions between multiple components.[53] Achieving a good understanding of what a Quality Improvement (QI) intervention is and how it works is always going to be less straightforward than understanding how and why a drug works. In contrast, QI interventions with drugs are never likely to be completely standardised or fully specified, indeed flexibility is essential for Qi interventions to work at scale across different contexts.[51] We need to understand how social science studies running alongside QI efforts can provide information that enhances the ability to adjust for context.[51] However, I believe that we can develop a better understanding how to improve complex systems through application of established models derived from Human Factors and Ergonomics.

Improving Systems: Human Factors and Ergonomics

The International Ergonomics Association Council's official definition of ergonomics is: "Ergonomics (or human factors) is the scientific discipline concerned with the understanding of interactions among humans and other elements of a system, and the profession that applies theory, principles, data and methods to design in order to optimize human well-being and overall system performance."[56]

Clinical Human Factors have been defined as: *"Enhancing clinical performance through an understanding of the effects of teamwork, tasks, equipment, workspace, culture, organisation on human behaviour and abilities, and application of that knowledge in clinical settings."* [56]

Human Factors & Ergonomics are about designing systems that are resilient to unanticipated events and addressing problems by modifying the design of the system to better aid people. Human Factors & Ergonomics are not about eliminating human error or addressing problems by teaching people to modify their behaviour.[57]

Human factors work ranges from the individual to the organisational level.[57] Human factors & Ergonomics aresystems-orientated because people are just one embedded component of a complex sociotechnical system and at the same time it is person centred. Human factors solutions use design of work structures and processes to improve patient, provider and organisational outcomes.[18] Human Factors & Ergonomics and Quality Improvement Science developed from similar origins in the 20th century to engage workers in the identification of problems and development of solutions. They diverged from Quality Improvement Science by focussing more on reducing variation, increasing the reliability of production and listening to the voice of the customer, whereas Human Factors & Ergonomics focussed on staff wellbeing (occupational health and safety) and performance.[58] It is time to integrate these complementary approaches together in research and training to improve the safety of healthcare.[58]

In the USA the Systems Engineering Initiative for Patient Safety (SEIPS) has developed a human factors model of person-centred sociotechnical systems (Figure 5). The first version of SEIPS was published in 2006[59] and the model has been refined by nearly ten years of application and research, including several relevant examples in medication safety and healthcare associated infection.[18] In the SEIPS model, organisations, teams and technology are seen as interrelated components, the properties of which are changed if the system is dissembled in any way. The model emphasises that movement in one part of a healthcare organisation leads in a predictable fashion to movement in other parts. Moreover, healthcare organisations are open to environmental inputs, so that they are continually in a state of flux. The SEIPS model has four components: the work system, work processes, outcomes and adaptation. The work system is configured as dynamic and interactive. This affords insights into how actions or occurrences at one level (e.g., an error made by an individual) interact with phenomena at team (e.g., detection and mitigation of the error) and organisational (e.g., safety culture) levels of analysis. The SEIPS approach to work processes recognises that the individuals engaged in healthcare include patients and carers as well as healthcare professionals. Outcomes in SEIPS are separated into patient, professional or organisational, each of which is further divided into either desirable or undesirable and either immediate (proximal) or delayed (distal).

Finally the SEIPS model includes adaptation as a feedback mechanism that explains how dynamic systems evolve in planned or unplanned ways.[18]

The SEIPS model provides a structure for investigation of the role of context in improvement. This is necessary if we are to move beyond statements that "context is important" to explanatory models that define what elements of context, under what circumstances, are important for human performance.[60] A relevant example is developing a hypothesis about improvement through identification of common factors between three organisations that have been the subject of public enquiries into *Clostridium difficile* infection outbreaks. These were NHS Trusts in Northern Ireland, Stoke Mandeville, and Maidstone and Tunbridge Wells.[60] Adopting a systems approach meant that common contributory factors were identified at multiple levels in the external environment (government, regulators), internal organisation (senior management, middle management), staff (clinical practice) and the internal environment (equipment, buildings). The investigators found that many individuals at ward level in all three Trusts were aware of the levels of poor hygiene and inadequate patient monitoring practices, but saw no way to improve the situation. The investigators concluded that many examples of staff behaviour within the three Trusts demonstrated characteristics of 'cultural entrapment' of the type described in an analysis of the high rates of infant mortality following heart surgery at Bristol Royal Infirmary. Cultural entrapment means that people often fail to question their actions and overlook important cues that things are not as they think they are. Consequently, system-wide organisational learning is inhibited and the inability to adapt and learn from failure results in patterns of negative reinforcement which, in turn, act as a barrier to change. The investigators hypothesis is that multi-level alignment and normalisation of risk related behaviours in these three Trusts led to entrapment of staff into sub-optimal behaviour patterns.[60] A successful intervention would need to change the culture in order to change behaviour by encouraging reporting of incidents and providing actionable feedback.[40]

The SEIPS model provides a structure to help practitioners to address the relationships between the multiple, nested levels of the work system, care processes, outcomes and the unintended consequences of change (Figure 5). Application to antimicrobial stewardship will be aided by evidence from over eight years of research on using SEIPS to improve medication safety and reduce healthcare associated infections.[18] However, aligning medical education with these studies of complex systems will be challenging.[61, 62] Consequently the final section of this paper discusses emerging approaches from educational research about learning about complexity in practice.

Learning in Practice

In the past fifteen years there has been significant innovation in the research of education and lifelong learning with greater emphasis on how individuals and materials interact and how they are related to the social context of complex systems.[19] These ways of thinking about education and learning are described as socio-material theories.[63] They focus on materials as dynamic and enmeshed with human activity in everyday practices:

> *"'Material' refers to the everyday stuff of our lives that is both organic and inorganic, technological and natural, flesh and blood, forms and checklists, diagnostic machines and databases, furniture and passcodes, snowstorms and dead cell zones and so forth. 'Social' refers to symbols and meanings, desires and fears and cultural discourses. Both material and social forces are mutually implicated in bringing forth everyday activities."*[64]

In the natural sciences, complexity science is the study of the dynamics, conditions and consequences of interactions.[65] Complexity theory describes a heterogeneous body of theories originating in evolutionary biology, mathematics, general systems theories and specific applications such as cybernetics.[63] In medical education there is growing awareness of the need to "embrace diversity and complexity" in educational research and practice.[62] Theoretical tools derived from complexity theory could and should be used to help develop healthcare students' capacity to take appropriate action in the complex, multifaceted and interdisciplinary care situations that characterise clinical practice.[61-65] In the broader field of professional education complexity theory is just one of several socio-material approaches. Despite their different origins and purposes these theories raise some common questions for educators aiming to support learning in practice (Table 4). These questions ask how learners interact with materials and how teachers enable them to notice and adapt to cues in the environment. Moreover they encourage learners and teachers to treat the environment as dynamic and to see a particular practice as nested within multiple complex systems:

> "*Students can learn to notice events that may be desirable or undesirable and, more importantly to intervene by actively experimenting with the socio-material setting."*[63]

There are striking similarities between these socio-material approaches to learning and the systems engineering approach to improving the complex work systems of patients and professionals (Figure 5). Consequently it is relevant to ask how do engineers learn about complex systems? The Royal Academy of Engineering recently commissioned a report to address the UK shortage of engineers through analysis of how schools, colleges and universities should teach engineering.[66] The report identified six habits of mind which, taken together, describe the ways that engineers think and act "to make 'things' that work or make 'things' work better" (Figure 6).[66] These are the same habits of mind that are required to improve healthcare.[67]

Can we teach medical students to think like engineers? At the University of Dundee we have been enabling medical students to investigate incident reports in order to promote their understanding of how errors occur and the systems in which they will be working.[68] We began with students in Final Year but more recently have been working with students in second or third year on improvement projects with support from the IHI (Institute for Healthcare Improvement) Open School[31] and BMJ Quality.[30] A recent, relevant example is a project to improve the recognition of post-operative acute kidney injury after urological surgery.[69] The need for this work was identified in a study of the impact on postoperative AKI (Acute Kidney Injury) of changing our hospital antibiotic policy for surgical prophylaxis.[70] An unanticipated finding from this study was that postoperative SCr (Serum Creatinine) was only measured in 52% of urology patients. This was concerning because the prevalence of postoperative AKI was 16% in the patients with complete data. Two second year students led an improvement project, which started with a task analysis of the processes for measurement of preoperative and postoperative SCr (Figure 7). The process map for postoperative SCr showed that the main problem was with patients discharged from the urology ward on the day of surgery (Day 0) or on the day after (Figure 7a). Measurement of SCr was requested on these patients but when phlebotomists came to the ward they were told the patient had been discharged. The students found that most of these patients were in fact in the day room waiting for medicines and for transport home. The process map for phlebotomy services (Figure 7b) established that it was possible for blood samples to be taken from patients in the day room so the system was changed to improve communication. This intervention increased reliability of postoperative SCr measurement in urology[69] and has been taken over by NHS Tayside's Patient Safety team in order to ensure sustained improvement. The students now understand that they will be working in complex systems where apparently simple tasks may not be performed reliably. More importantly they have learned that they can identify and test solutions that improve the system. This work has been made possible by NHS Tayside's Patient Safety Network, which explicitly recognises the valuable work that students can do to improve clinical care through projects that teach them about the health system.[71] We are currently involving about 30 students per year in improvement projects but the University of Dundee has 160 medical students and 300 medical students in each intake year, with about 1700 students in NHS Tayside in any calendar year. Through the Academic Health Sciences Partnership in Tayside[72] we aim to scale up to having at least 200 inter-professional improvement teams led by students and Early Career Professionals (ECPs) within the next three years. ECPs are defined as those in their first five years since qualification or in their first five years of management training. We are working with Scottish Improvement Sciences Collaborating Centre on evaluation.[73] We hypothesise that forming inter-professional improvement teams like this will enhance capacity and capability within and across organisations.[73] We plan to evaluate this process by exploring:

• barriers and facilitators to successful completion of improvement projects by students and ECPs

• costs incurred by clinical teams and organisations from hosting QI projects

• the impact of QI projects on clinical team culture

• the ways in which QI projects facilitate organisational change

When people look out on their context, do they perceive an abundance of opportunity or a scarcity of opportunity? Research shows that people at the top of an organisation are more likely to see an abundance of opportunity whereas people at the bottom perceive their context as threatening or limiting and are unwilling to participate in change.[50] We believe that supporting students and Early Career Professionals to lead improvement projects will enable them to see an abundance of opportunity and that this will also facilitate systems improvement at scale.

Conclusions and Actions for the Stewardship Community

There are three relatively simple actions that can be taken to enhance the science of improvement for antimicrobial stewardship. Firstly, improve the design and reporting of interventions to change practice through dissemination of evidence about effective behaviour techniques. Secondly, ensure that interventions start by asking why people do what they do. Thirdly, think about why any intervention might work and ask what works for whom and under what circumstances? However, achieving sustained improvement at scale will only come through profound understanding of the role of context. We need explanatory models that define what elements of context, under what circumstances, are important for human performance. We also need to recognise the importance of case studies for discovery and for developing and testing explanations for the consequences of interventions.[51] Case studies traditionally occupy the lowest rung in the hierarchy of medical science but that view needs rethinking.[74] Medical journals should be aware of the innovative methodological work that is taking place on case studies in the social sciences.[51]

Human Factors and Ergonomics and Improvement Science address context in different but complementary ways. Human Factors and Ergonomics designs interventions based on understanding human capabilities and limitations whereas improvement science focuses on how systems can enable front line staff identify problems and test solutions.[58] Both approaches are socio-material and would benefit from innovations in educational research and learning in other professional fields, particularly design and engineering. Integration of these disciplines as complementary rather than competing approaches to antimicrobial stewardship will require development of a shared agenda through identification of themes that could be relevant across these different traditions of social science. At the same time we need to rethink professional education in antimicrobial stewardship by embracing complexity, learning in practice, learning in teams and changing culture by using students and Early Career Professionals as Change Agents**.**

Transparency declarations:

I am the co-chair of the Quality and Safety Workstream of the Academic Health Sciences Health Partnership in Tayside and lead for the Capacity and Capability Building Research Theme of the Scottish Improvement Science Collaborating Centre, which are both cited in the references. No other conflicts of interest.

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Figure 1: Goal setting, feedback and action planning for 123 interventions reported in 116 articles about improving antibiotic prescribing to hospital inpatients. Drawn from data in Davey et al 2015.[17]

Figure 1a: Goal setting

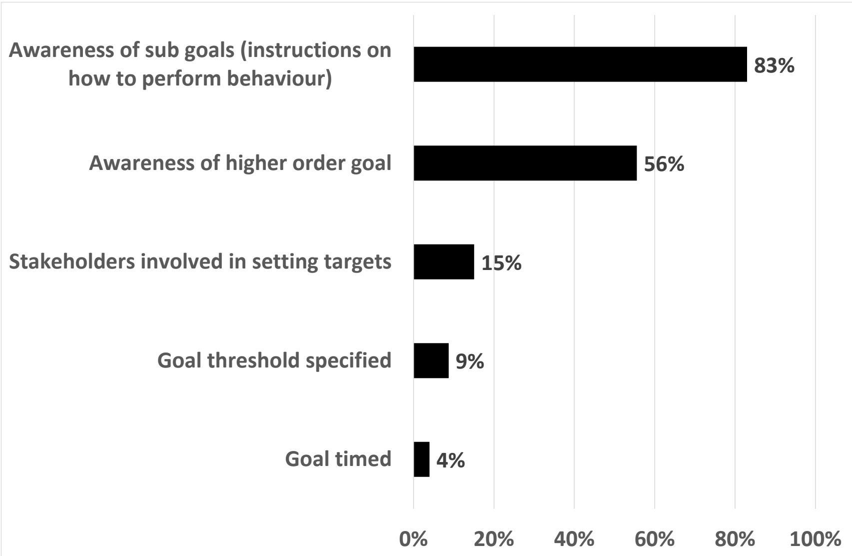


Figure 1b: Feedback and action planning

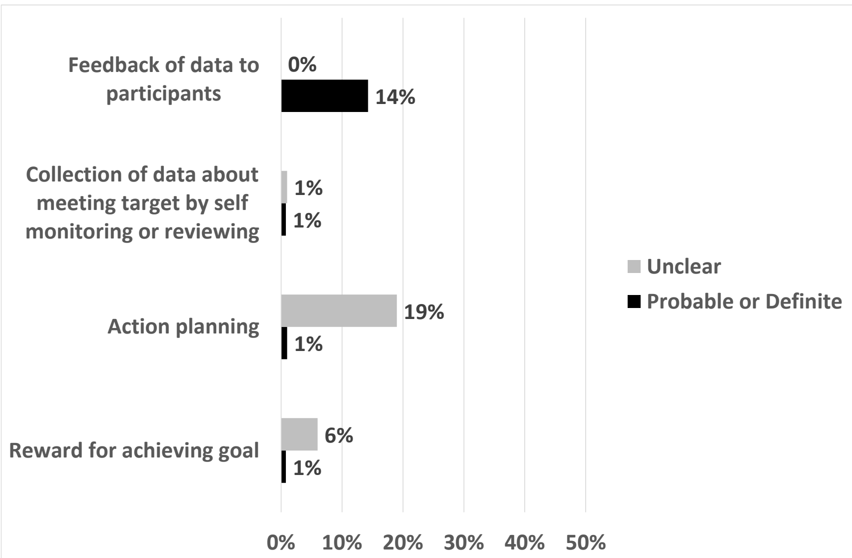


Figure 2: The missing link in the audit cycle. Although many audit studies describe deficiencies in health care, few identify the underlying causes. In consequence, the strategies for change which are developed may not address the fundamental problems. An important link in the audit cycle is missing, and failure to include this step is hampering the success of audit. Adapted from Crombie et al 1993[28] with permission.

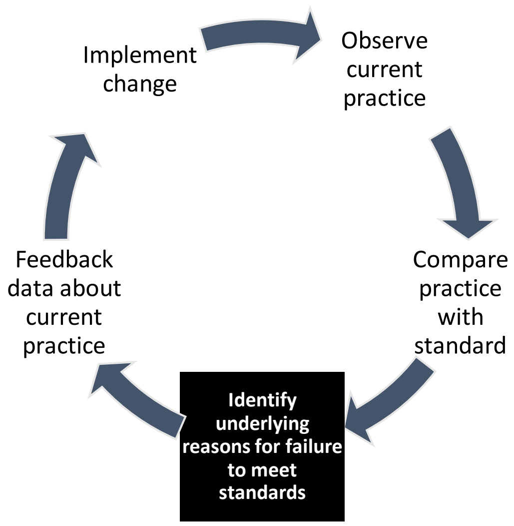
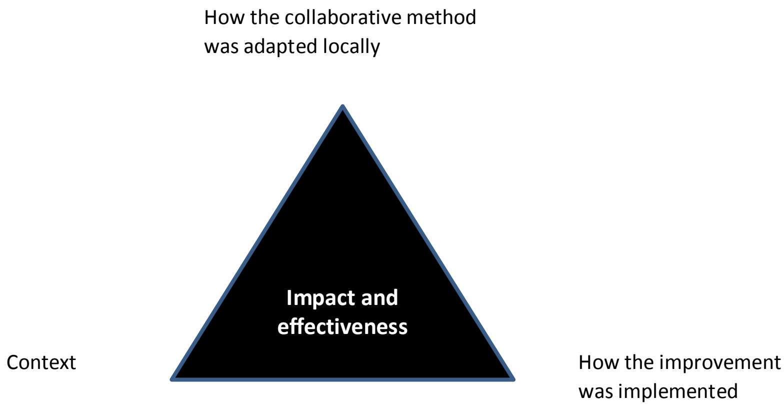


Figure 3: Eight Principles of Sustainable Measurement. From Nelson et al 1998[41] with permission

1. Seek usefulness, not perfection in the measurement
2. Use a balanced set of process, outcome and cost measures
3. Keep measurement simple, think big but start small
4. Use qualitative and quantitative data
5. Write down the operational definitions of the measures
6. Measure small, representative samples
7. Build measurement into daily work
8. Develop a measurement team

Figure 4: Factors explaining variation in the effectiveness of the UK Orthopaedic Services Collaborative in 2002. The primary outcome measure was length of stay and there was mean reduction by 13% for all hospitals in the collaborative. However, the range was from 3% increase to 43% decrease in length of stay. Three factors were identified to explain most of this variation but the most important of these was context. Adapted from Bate 2014.[50]



Components of context:

1. Leadership
   - Style
   - Level of executive support
   - Local team leaders
2. Political
   - Empowerment
   - Mix of allies, adversaries and fence sitters
3. Cultural
   - Shared mind sets around quality and participation

Figure 5 The SEIPS (Systems Engineering Intervention in Patient Safety) Model, Version 2.0. Reproduced with permission from Holden et al 2013.[18]

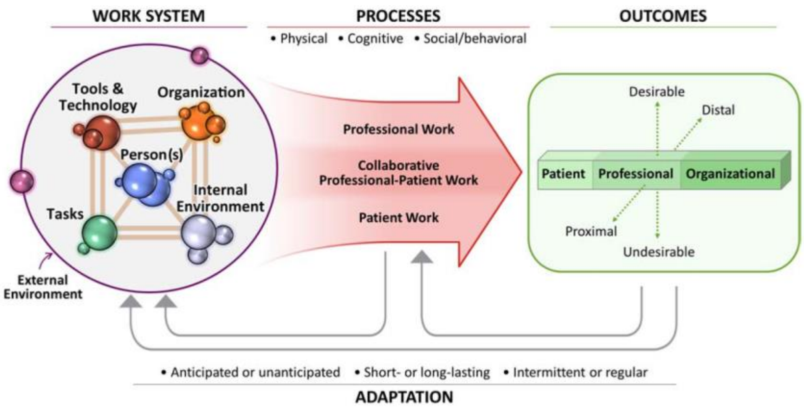


Figure 26 How to think like an engineer: six engineering habits of mind. From Lucas et al 2014[66] with permission

1. Systems thinking: Seeing whole systems and parts and how they connect, pattern-sniffing, recognising interdependencies, synthesising.
2. Problem-finding: Clarifying needs, checking existing solutions, investigating contexts, verifying.
3. Visualising: Being able to move from abstract to concrete, manipulating materials, mental rehearsal of physical space and of practical design solutions.
4. Improving: Relentlessly trying to make things better by experimenting, designing, sketching, guessing, conjecturing, thought-experimenting, prototyping.
5. Creative problem-solving: Applying techniques from different traditions, generating ideas and solutions with others, generous but rigorous critiquing, seeing engineering as a 'team sport'.
6. Adapting: Testing, analysing, reflecting, rethinking, changing both in a physical sense and mentally.

Figure 7: Process maps from a student led project to improve the identification of post-operative acute kidney injury for urology patients who received gentamicin prophylaxis. From Trotter et al 2014[69] (Slides 4 and 5 from Supplementary Material, Attachment 1- Baseline Data and Process Maps, available at http://qir.bmj.com/content/3/1/u205219.w2164/suppl/DC1) with permission.

Figure 7a: process map for measurement of post-operative creatinine by day of surgery
Key: DSU, Day Surgery Unit; Ward 9, Urology inpatient ward

Commented [PD1]: Figures replaced as requested by DR

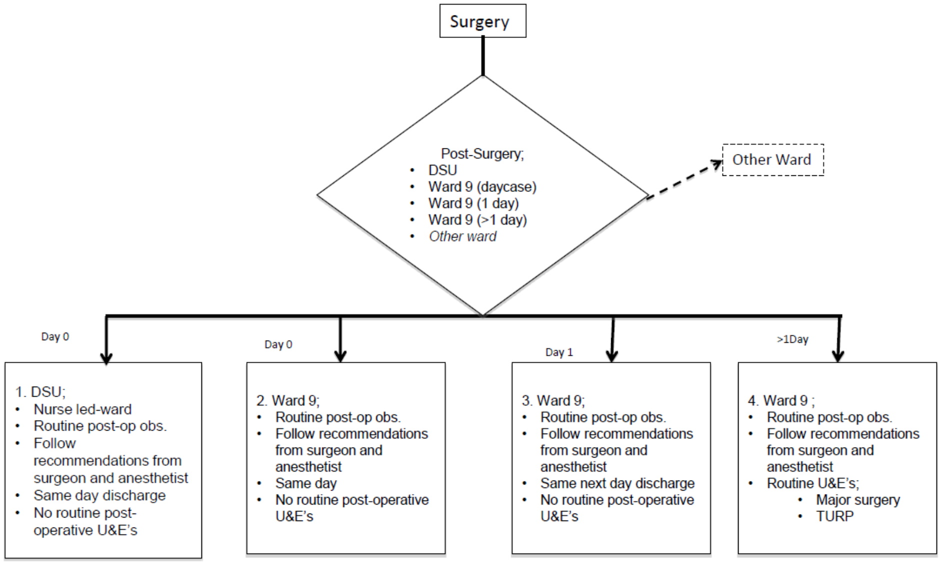


Figure 7b: process map for phlebotomy services on the urology ward

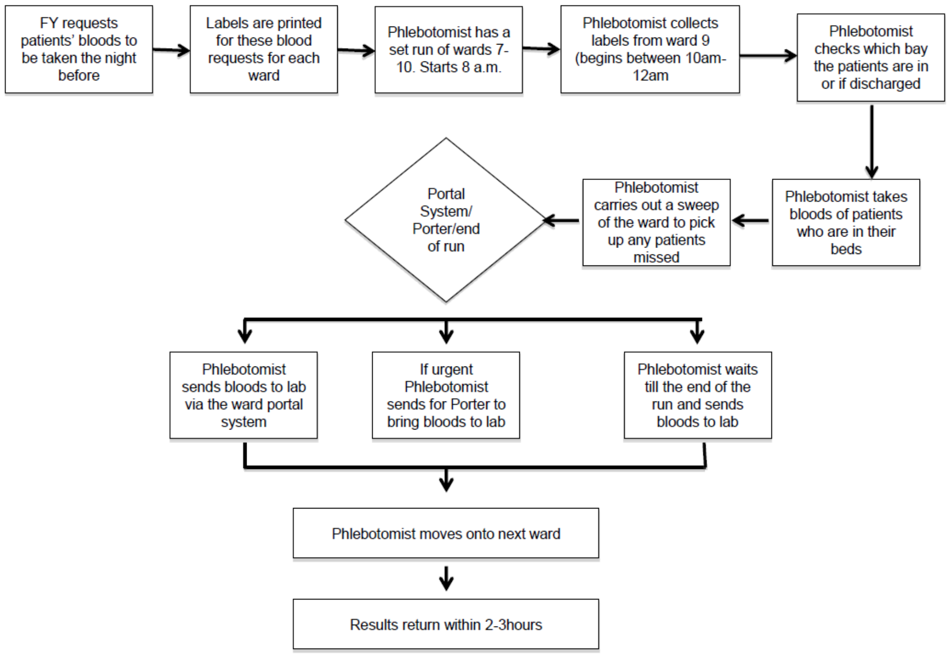

FY requests patients' bloods to be taken the night before
Labels are printed for these blood requests for each ward
Phlebotomist has a set run of wards 7-10. Starts 8 a.m.
Phlebotomist collects labels from ward 9 (begins between 10am-12am
Phlebotomist checks which bay the patients are in or if discharged
Phlebotomist takes bloods of patients who are in their beds
Phlebotomist carries out a sweep of the ward to pick up any patients missed
Portal System/ Porter/end of run
Phlebotomist sends bloods to lab via the ward portal system
If urgent Phlebotomist sends for Porter to bring bloods to lab
Phlebotomist waits till the end of the run and sends bloods to lab
Phlebotomist moves onto next ward
Results return within 2-3hours

Table 1: Design of a Text Based Intervention designed to reduce use of antibiotics by dentists, modified from data in Prior et al 2014[32] (Additional File 1, online only at http://www.implementationscience.com/content/9/1/50/additional). The intervention was added to feedback data about antibiotic use in the previous month.[32] Guideline recommendations are from Scottish Dental Clinical Effectiveness Programme – Drug Prescribing for Dentistry: Dental Clinical Guidance, 2nd Edition.

Key: BCT Behaviour Change Techniques, the numbers refer to the classification in Michie et al:[24]
BCT 36. Instruction on how to perform the behaviour (advise or agree on how to perform the behaviour)
BCT 78. Provide information about health consequences of performing the behaviour (note: consequences can be for any target, not just the recipient of the intervention)

Guideline Recommendation	BCT	Wording in the Text Based Intervention
Prescribing prolonged courses of antibiotic treatment can encourage the development of drug resistancce	78	Merged to reduce text and edited (remove “prolonged” and change “drug” to antimicrobial: “*Prescribing courses of antibiotic treatment can encourage the development of antimicrobial resistance and therefore must be kept to a minimum*”
Prescribing of antibiotics must be kept to a minimum	36	
As a first step in the treatment of bacterial infections, use local measures. E.g. drain pus if present in dental abscesses by extraction of the tooth or through root canals, and attempt to drain any soft-tissue pus by incision.	36	Included without modification other than this additional text, based on evidence from dentist colleagues about potential influences on antibiotic prescribing: “*This should be the first step even if patients request antibiotics and even when time is short.”*
It is appropriate to prescribe antibiotics for oral infections where there is evidence of spreading infection (cellulitis, lymph node involvement, swelling) or systemic involvement (fever, malaise)	36.	Included but merged and shortened: “*Antibiotics are appropriate for oral infections where there is evidence of spreading infection, systemic involvement or persistent swelling despite local treatment”*
Other indications to prescribe antibiotics are acute necrotising ulcerative gingivitis and sinusitis, and pericoronitis where there is systemic involvement or persistent swelling despite local treatment	36	

Table 2: Challenges to actionable feedback for an intervention to improve appropriate antibiotic prescribing in a Neonatal Intensive Care Unit.[36]

Process measure characteristic	Challenges	Key actions	Outcomes	Achieved
Timely	1. Data collection 2. Data presentation 3. Rare outcomes	1. Partial automation 2. Existing meetings 3. email	1. One month data delay 2. Two monthly meetings 3. Email pre meeting	**Partially**
Individualised	1. Rotating staff 2. Assigning responsibility for specific antimicrobial usage	Focus groups with prescribers to evaluate acceptance of individual feedback	1. Group feedback desired & provided 2. De-identified data	**No**
Nonpunitive	Concern about peer or supervisor judgement	1. Written informed consent from neonatologists 2. Certificate of confidentiality from National Institute for Nursing Research	98% eligible physicians enrolled and signed consent	**Yes**
Customised	Limitations of local evidence-based policies	1. Ethnography 2. Multi-centre antibiotic data[34] 3. Clinical vignettes[35]	1. Prescriber involvement 2. Inter-disciplinary committee	**Yes**

Table 3: Determinants of antibiotic prescribing in hospitals, from data in Charani et al 2013[37] Etiquette is presented alongside the three main themes because it was found to be a cross cutting theme

<table>
<tr>
<td>1. Decision-making autonomy</td>
<td>"Sometimes during a procedure, if the surgeon feels there's a need to introduce antibiotics, they say so and I have never challenged that, no one has ever challenged that."

Nurse, Orthopedics (12 y)</td>
<td rowspan="3">4. Etiquette:

"I think doctor to doctor, it's very difficult for clinician to clinician, especially different specialties to go and criticize one another. I think that's not collegial practice, so people don't want to do that."

Nurse, Outpatient Parenteral Antimicrobial Therapy Services (14 y)</td>
</tr>
<tr>
<td>2. Limitations of local evidence-based policies</td>
<td>"Sometimes it is difficult to . . . use the policy because the policy will be your average sort of thing, it's not looking at someone at the top or at the bottom."

Pharmacist, General Medicine (2 y)</td>
</tr>
<tr>
<td>3. Culture of hierarchy</td>
<td>"The junior doctors tend to change it and the junior doctors won't change it if their senior doctors, if the consultant or registrar's specifically asked them to prescribe something else." . .

Pharmacist, Intensive Care Unit (7 y)</td>
</tr>
</table>

Table 4: Common aspects of socio-material approaches to understanding education and questions these understandings raise for educators. Reproduced with permission from Fenwick and Dahlgren 2015.[63]

Key socio-material understandings	Questions raised for educators
A focus on *materials* as dynamic and enmeshed with human activity Human meanings and decisions are important but are not the only things acting in any situation	How do particular materials and built environments affect what our students do and think? How might we encourage students to notice how materials influence situations in which they practise?
Emphasis is not on individual things and their characteristics, such as individual doctors' skills or particular technologies, but on their*relationships* and what these produce	How might students become more actively aware of these relations and their effects?
Practices themselves are continuously changing *gatherings* of human and non-human elements that act on one another in unpredictable ways	How do different elements act on one another to affect what happens, and how do these different interactions produce particular kinds of knowledge?
The *whole system* affects any particular practice as it continuously adapts and changes pattern	How is a particular practice interconnected with and affected by other systems?
Uncertainty and unpredictability are assumed	What might be inhibited in professional education dominated by predetermined curricula and planned objectives?