Nanotechnology for healthcare

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Introduction

Nanotechnology has the potential to make a significant impact on healthcare by delivering step-changes in disease diagnosis and monitoring, implants and regenerative medicine, drug delivery, as well as research tools for drug discovery and biomedical science.

Exploiting the different and enhanced properties that nanoscale materials exhibit – due for example to increased relative surface area, the emergence of quantum effects and nanoscale interactions with biological systems – presents challenges and opportunities for scientists, engineers and wider society.

The very properties that make nanomaterials so exciting, such as increased reactivity and the potential to cross cell membranes, may also have negative environment, health and safety (EHS) impacts.

In addition, advances in healthcare technologies may also change social relationships in ways that pose ethical issues. For instance, technologies can change the relationship between patient and doctor issues, redefining the distinction between experts and patients. They can also precipitate more complex changes: from which diseases are prioritised and who gains access to treatments; to transforming our understanding of what it is to be human, through the use of novel technologies for enhancement.

For nanotechnologies to make a positive impact on our lives, as well as funding the best science, setting research priorities also entails having to consider this wider context - to reflect on different potential outcomes for society.

This project was developed to enable the Engineering and Physical Sciences Research Council (EPSRC) to take account of a wide set of societal views and inform nanotechnology research trajectories for healthcare - creating a space through which citizens, scientists and stakeholders can engage in an informed debate on the public value, ethics and applications at an early stage.

Specifically, it forms part of a range of consultation activities providing intelligence to inform the EPSRC in developing a Grand Challenge call for proposals under the cross Research Council programme Nanoscience through Engineering to Application. This is for large-scale, integrated research projects to exploit nanotechnology in the healthcare domain.

The principle objectives for this project were to:

i. To identify public concerns and priorities in relation to the development of nanotechnology for healthcare;

ii. To identify public priorities for nanotechnology for healthcare research given (i);
iii. To inform researchers undertaking projects subsequent to the call;
iv. To inform decisions in the call;
v. To use as an example for EPSRC to learn about public dialogue and how to use it.

Importantly, the project also provides:

- input to EPSRC's decision making process regarding the scope of the nanotechnology for healthcare Grand Challenges call:

- an ongoing point of reference for researchers funded under the Grand Challenge call as to public interests in nanotechnology for healthcare.

The methodology used to examine these issues is described next.

1 Methodology

1.1 Introduction

The approach developed used a variety of methodologies and stimulus techniques to engage the public and specialists in informed discussions around nanotechnology.

Specifically, to address the research objectives, a four phase process was developed:

Phase 1 involved a detailed scoping of activities and issues to be examined in the dialogue, taking into account findings from a wider consultation process undertaken by the EPSRC to inform the Grand Challenges call.

Phase 2 involved the recruitment of public and expert participants to take part in the process.

Phase 3 involved the delivery of two reconvened deliberative workshops at four locations across the UK. The first workshop focused on the visions and wider social and economic drivers of nanotechnology research for healthcare. The second examined specific healthcare applications for nanotechnology.

Phase 4 involved the analysis of the workshops and production of the final report. It specifically highlighted both general issues related to nanotechnology for healthcare, as well as providing outputs for use by scientists applying for the Healthcare Grand Challenge. The figure below summarises these stages.

Figure 1: Methodological approach

Each of these stages is now explored.

1.2 Phase 1: Scoping and recruitment

1.2.1 Project scoping and design

A project scoping meeting was set up on 12 March 2008 to discuss the overall aims and objectives of the study and to refine the methodological approach.

Specifically the meeting agreed the:

1. **Workshops areas:** London, Swansea, Sheffield and Glasgow were chosen as they provided a wide demographic and geographic coverage. They also were near to leading centres of UK nanotechnology to assist in the recruitment of experts.
2. **Design of the workshop:** two reconvened workshops would be undertaken, providing the opportunity for members of the public to learn about nanotechnologies and discuss the wider governance issues in workshop 1; and discuss specific applications in workshop 2
3. **Number of public participants and recruitment criteria**: 20 members of the public in each area would be recruited, reflecting the socio-economic profile of their region
4. **Potential experts**: a scientist or engineer together with an ethicist or social scientist would be involved in each workshop. Their role would be to aid the deliberation of the public and reflect on public views from their own professional standpoint.

A revised methodology and project delivery plan was then agreed with EPSRC and work began drafting the stimulus material and case studies for the workshops. All materials were sent to the Project Steering group for comments, which comprised nanotechnology experts and decision makers at EPSRC, before final drafts were produced. All final versions were signed off by EPSRC.

1.2.2 Other consultative processes with experts

It should be noted that, in addition to the public dialogue, the Healthcare Grand Challenge programme for nanotechnology also involved two additional consultative processes which were aimed at engaging with the research community in order that researchers could give up to date information on the direction in which they thought the research was heading. These were:

- **A web based consultation** – this ran from 10th January until 28th March 2008. Ninety-seven submissions were received.

- **A town meeting** – this discussed the call face to face with the research community. This meeting was held on 3rd April 2008.

Specifically, key findings from these consultative processes highlighted the following potential application areas:

Nanotechnology for Diagnostics - two sub-areas were distinguished; the use of in-vivo techniques for in-patient monitoring, and the use of in-vitro techniques, for analysis outside the patient.

Environmental control of pathogens – which focused on integrated solutions to detect and eliminate pathogens on surfaces.

Nanotools for drug discovery – this focused on the development of underpinning technology to facilitate the process of screening new drug targets, at the single molecule level.

Nanotechnology for regenerative medicine – this focused on the creation of engineered, smart, functional nanomaterials that serve to direct cell interactions and control tissue developments.

Nanotechnology for drug delivery – this included delivery to difficult to reach tissues; and the drug delivery requirements of emerging drug candidates.

Nanotechnology for combined diagnostics and delivery of therapies or "theranostics" - this included the possibility of combining diagnosis and delivery of a therapeutic agent in a single system, most likely targeted at a single disease condition.

Whilst not forming part of this specific piece of research, it was important that the workshops took account of these findings. Specifically, the six application areas formed the focus on the second public workshop.

1.3 Recruitment

1.3.1 Public recruitment

The recruitment of members of the public to participate in the deliberative workshops was undertaken by BMRB's in-house qualitative recruitment unit. Prior to the commencement of recruitment, a briefing was undertaken to ensure that the field team and recruiters were familiar with the project aims and the

recruitment profiles of the four areas involved (see table 1). Twenty-two participants were recruited to achieve a sample of 20.

Table 1: Recruitment Profiles by Region

Region (Venue)	Gender	Social grade	Age	Ethnicity	Total Number
London	M 11 F 11	ABC1 12 C2DE 10	16-34 8 35-54 7 55+ 7	White 14 Black 4 Asian 4	22
Swansea	M 11 F 11	ABC1 11 C2DE 11	16-34 7 35-54 7 55+ 8	White 15 Black 4 Asian 3	22
Sheffield	M 11 F 11	ABC1 10 C2DE 12	16-34 7 35-54 7 55+ 8	White 18 Black 2 Asian 2	22
Glasgow	M 11 F 11	ABC1 10 C2DE 12	16-34 7 35-54 8 55+ 7	White 15 Black 3 Asian 4	22

Recruiters used 'Free Find' techniques, where members of the public were approached face to face and asked to undertake a screening questionnaire to assess eligibility and ensure that designated quotas were accurately filled. At this time, respondent availability to attend both workshops was confirmed.

Once recruited, the participants were sent a confirmation letter and received a reminder phone call in the week leading up to each of the two workshops. The field team also made recruitment checks prior to the workshops to ensure that the quotas set in the relevant recruitment profile had been filled.

Participants received incentive payments of £75 for the first workshop, increasing to £80 at the second. This level of incentive helped to ensure interest among the 'ordinary' public who might otherwise be put off by what could be seen as a complex and difficult topic.

1.3.2 Specialist recruitment

In addition to members of the public, BMRB also recruited a scientist or engineer, and a social scientist or ethicist to take part in the workshops. The role of specialists was twofold. First was to provide a resource for the public in their deliberations on nanotechnology. Second was to listen to and reflect on the public's aspirations and concerns for nanotechnology.

Initial contact lists for the specialists were provided by EPSRC and snowballed out from researchers in the field. This part of the recruitment was handled by the core research team.

The following procedures were undertaken:

1. An email was sent inviting the specialist to the workshop
2. A telephone call was made, discussing the workshop focus and the role of the specialist in more depth.
3. A confirmation email was sent, highlighting venue and logistical arrangements, as well as recapping on key issues that had emerged during the briefing.

The following specialists attended the workshops.

Table 2: Specialists at the deliberative workshops

Area	Workshop 1	Workshop 2
London	• Dr Rachel McKendry, University College London; • Professor Geoff Hunt, University of Surrey.	• Professor Gabriel Aeppli, London Centre for Nanotechnology; • Dr Rob Doubleday; University of Cambridge.
Swansea	• Dr Chris Wright, University of Swansea; • Kajsa-Stina Magnusson University College London.	• Dr Kar Seng Teng, University of Swansea; • Kajsa-Stina Magnusson University College London.
Sheffield	• Dr Giuseppe Battaglia, University of Sheffield; • Dr Alison Mohr, University of Nottingham.	• Dr Giuseppe Battaglia, University of Sheffield; • Professor Phil MacNaghten, University of Durham.
Glasgow*	• Professor Lee Cronin, University of Glasgow; • Professor Brian Wynne, University of Lancaster.	• Dr Matthew Dalby, University of Glasgow.

*A social scientist had to pull out of the second Glasgow workshop.

1.4 Phase 2: Reconvened Deliberative Workshops

Two reconvened deliberative workshops were then designed to explore a range of issues related to nanotechnology for healthcare and to facilitate discussion with experts on these issues. The workshops were held on the following dates:

Table 3: Dates of the deliberative workshops

Area	Workshop 1	Workshop 2
London	5 April 2008	10 May 2008
Swansea	12 April 2008	10 May 2008
Sheffield	12 April 2008	10 May 2008
Glasgow	12 April 2008	10 May 2008

1.4.1 Workshop 1 - *Visions for nanotechnology*

Workshop 1 aimed to:

- enable participants to frame nanotechnology from their own perspective;
- learn from experts in the field about nanotechnology;
- consider some of the wider issues for governance around nanotechnology;
- consider ethical, health and safety issues
- consider potential uses for healthcare
- consider different visions of nanotechnology for healthcare

Experts gave their presentations in plenary sessions to ensure that all participants at a particular workshop received the same information. For discussion sessions the participants were divided into two smaller groups of ten and taken through a topic guide by a trained moderator. Printed stimulus materials were provided and discussed in these small groups.

Specifically workshop 1 explored the following issues (see appendix 1 for the full topic guide)

Theme	Issues covered
Unprompted views of healthcare technologies and healthcare related issues including:	Experiences of healthcare technologies Diseases of particular concern Views on: Health inequalities Preventative medicine Quality of life and age related diseases Infection control Early diagnosis of diseases and health monitoring The use of medicines and drugs in society Drug delivery Personalised medicines
Previous knowledge of nanotechnology	Awareness and understanding of nanotechnology
A presentation and Q&A on the use of nanotechnology research for healthcare by the scientist and social scientist	What is nanotechnology research What are its potential applications and challenges What are the key drivers shaping nanotechnology research What are some of the environmental, health and safety issues facing nanotechnology What are the wider ethical / social issues What is the UK's international position in nanotechnology research What is the UK investment in nanotechnology and what are the wider innovation and commercial issues How does the UK regulate research / comparison to other countries
Group discussion of handouts on nanotechnology	Reactions to nanotechnology research Reactions to applications Reactions to risks and regulation Reactions to commercial drivers
Discussion of three 'visions for nanotechnology'	A scientific perspective A social scientific perspective An industrial perspective

The workshop also included an interactive voting session, canvassing views on nanotechnology before and after the discussion to examine the impact of debate on participant's views.

At the end of the workshops, participants were given details of the next event and given the addresses of websites (EPSRC; Wellcome Trust and Science Museum) where they could research further information on nanotechnology.

1.4.2 Workshop 2 – Nanotechnology applications for healthcare

Workshop 2 took an in depth look at six potential applications for nanotechnology in healthcare. For each application, participants were asked to consider their aspirations and concerns for the technology; and think about the application in relation to wider principles governing what they want out of medical technologies and healthcare more generally.

To prompt discussion, each application was provided as a case study handout. Handouts sought to present both the potential costs and expected benefits whilst highlighting any relevant commercial or ethical concerns that the application might raise.

Though they did not formally present, a scientist and a social scientist were available to act as a resource for the group in order to aid their deliberations. Again, participants were divided into two groups of 10 and taken through discussion in relation to a topic guide by a trained moderator.

As with the previous workshop, IML interactive voting was used to track views on the priorities of nanotechnology for healthcare – with a poll taken prior to and post discussion.

Specifically workshop 2 explored the following issues (see appendix 2 for the full topic guide)

Themes	Focus
Welcome and introduction	Unprompted voting on application priorities for healthcare.
Diagnosing Illness	Discussion of lab on a chip technologies and the idea of a healthcare MOT
Infection control	Discussion of the detection and elimination pathogens in healthcare, food safety and bioterrorism
Drug discovery	Enhancement of the drug discovery process, through the miniaturization, automation, speed and reliability of assays
Regenerative medicine	Production of materials that can help control how tissues develop and how cells interact
Drug Delivery	Review of uses for targeted anti-cancer deliveries; biologics and hard to reach tissues
Theranostics	Discussion of devices that combined the diagnosis of a disease and the delivery of a therapeutic agent in a single system

After the workshop, participants were thanked for their time and told about the next steps in the process. Specifically, they were informed that the findings would be presented to the EPSRC's Nanotechnology Strategic Advisory Team (the Nano SAT) to inform the Grand Challenge call; and that a report accounting for their views would be written to inform researchers bidding into the fund.

Further to the workshops, a letter was written from EPSRC to participants as the call was announced, thanking them for their time. EPSRC also intend sending participants a further letter once the call has been completed informing them of which projects were funded.

1.4.3 Analysis

The workshop sessions were digitally recorded and audio transcribed. The transcripts were then analysed through a technique called *Matrix-Mapping*. Based on the topic guide, the researchers' experiences of conducting the fieldwork and their preliminary review of the data, a thematic matrix was constructed and the transcript material was then summarised into this framework.

The material was then reviewed and concepts, typologies and associations identified within the data. These themes were then used to construct the reports.

The data collected from IML voting was also used as part of the analysis. It should be noted that the dataset generated was relatively small and was not designed to be subjected to quantitative statistical analysis. The main value of this data was in capturing how the range of views on research applications translated into priorities and how these views changed over time.

1.5 Research outputs

There were three main outputs developed from the research.

First: **a presentation** was given to the Nanotechnology Strategic Advisory Team on 21 May 2008 which provided an overview of the findings. The purpose of this meeting was to consider both the public engagement and other consultation processes in informing the focus of the Grand Challenge call. As a consequence of this meeting, the Grand Challenge call focused on two main areas: nanotechnologies for the targeted delivery of therapeutic agents and; nanotechnologies for healthcare diagnostics. Other applications were subsumed into these main themes.

Second: a **main report** provided a full descriptive account of the methodology and workshops findings in relation to the topic guide.

Third: a **summary report** highlighted specific findings for researchers bidding into the Grand Challenges call under the two areas of nanotechnologies for therapeutic agents and healthcare diagnostics. This stand alone document will form an important part of the application process, with researchers being required to describe how they have taken account of public aspirations and concerns within their bids.

Our findings are explored next.

2 Findings - Healthcare and nanotechnology

2.1 Healthcare technologies

At the start of each workshop, participants were asked to give their spontaneous thoughts on healthcare technologies. Frequently participants expressed their hope the medical advances could help treat conditions that they perceived to have the most negative impact on individuals and society. These fell into four groups:

- Life-threatening (e.g. Cancer, Heart Disease)
- Headline diseases (e.g. MRSA, Avian Influenza)
- Debilitating conditions (e.g. Alzheimer's, Rheumatism)
- Behavioural and mental health issues

Certain groups highlighted significant technical progress in healthcare during their own lifetimes, in terms of the overall improvement in mortality and quality of life. Specifically, advances in science and technology were seen to have made the treatment of disease increasingly effective.

> *"I always think of keyhole surgery when I'm thinking of science or medical issues[…] obviously they're doing things a lot easier now [people] recover […] quickly if they only do a small aperture rather than ripping you open"* ***Male, Sheffield***

Technologies worked best when enabling lifestyle changes

Technologies were believed to be most beneficial when enabling people to adopt lifestyle changes to improve their health. Whilst participants felt that future scientific advances in technology had a central role to play in addressing the impact of disease on society, an individual's best chance of leading a healthy life came from a sense of responsibility for their own well being and lifestyle education.

> *"if enough of the resources are spent educating people how to balance their bodies or look after their health from an early stage… that would help a lot"* ***Male, London***

> *"Don't take anything to excess, don't over eat, don't over drink… it's common sense rather than technology"* ***Female, Swansea***

As a consequence of this, technologies that focused on disease prevention - for instance those that could improve rates of early detection and diagnosis such as CAT scans – were greatly valued by participants. Several participants considered that 'preventative medicine' could help people to manage their health, which would have a positive effect on their quality of life.

> *"if you stop something before it gets bad and out of control you can save a lot more people… a lot of money should be put into prevention, definitely. That might cut down on costs in the future as well, saving a lot of people's lives"* ***Male, Sheffield***

Health MOTs were also discussed in relation to preventive medicine. It was argued that whilst this treatment could have a big impact on the capacity of GPs to keep up with demand in the short term, it could have a long term benefits through the reduced need for treatments.

> *"if people are not having [check ups] and getting diagnosed, surely it is going to cost a hell of a lot […] If they catch it early they will save money"* ***Female, Glasgow***

A system of early diagnosis utilising new technologies would reduce the overall burden on the health system and create an environment where health care budgets could focus on diseases that are not easily predicted or controlled.

Using low-tech and behavioural solutions to address ill health

In this context, there was a discussion related to the importance of behavioural versus medical interventions to combat ill health.

> *"We are living longer because we are eating better foods and we are listening to what they are telling us, I don't think it has anything to do with drugs"* ***Female, Swansea***

Several participants were concerned that the spread of 'superbugs' such as MRSA was easily preventable if end users and staff rigorously followed simple hygiene procedures.

Technologies thus should be developed hand in hand with other behaviour interventions to maximise success.

An over burdened health system and insufficient resources

Whatever the intervention, the financial implications and resource allocation in the NHS was a key concern for participants. Whilst money for technical innovations was supported, this needed to be accompanied by savings derived

from greater levels of efficiency within the health care system. Many participants felt that a lot of resources are wasted unnecessarily on administration and bureaucracy.

> *"I still think we have the best health service in the world… I wouldn't mind paying a bit extra really to make sure that it is kept up, it should be monitored because I am told they are wasting a lot of money by employing a lot of admin people"* ***Male, Swansea***

Overall, there was a perception that the health system was so overburdened by preventable illnesses and bureaucracy that potentially there would not be sufficient resources available to adopt new treatments such as those made possible by nanotechnology. Concern was expressed that we already had a system that promoted health inequalities and adoption of these technologies could serve to widen these gaps.

> *"[It already] seems to be […] that if you live in one area you can get the medication but if you live somewhere else the Council won't [allow it]"* ***Female, London***

Trust and transparency

Beyond resource allocation, a wider discussion ensued on institutional trustworthiness. Specifically, transparency was a concern within the groups, with certain participants feeling that health professionals and research scientists do not adequately inform, or are not entirely honest with people regarding the potential dangers and side effects of particular treatments. Side effects of drugs such as anti-depressants and clinical trial failures such as Northwick Park were highlighted.

> *"Well I think they are responsible, they owe an obligation to the person when they're administering a drug, to [let them] know fully what that drug can do and any possible side effects, I don't think today […] when we go to the doctor, we ask enough questions […] because sometimes the side effects could outweigh what you've gone to the doctors for"* ***Female, Swansea***

> *"We have got to feel confident. I mean it is only when things go wrong, like when those poor people who were being tested for that drug and they had terrible side effects that I started thinking they don't do enough"* ***Female, London***

2.2 Reactions to nanotechnology

Participants were fairly positive about the advancements in nanotechnology that were presented in the course of the workshop. However, participants still found nanotechnology a confusing subject and hard to conceptualise. People felt that whilst they felt fairly confident in understanding the potential benefits of nanotechnology they were not so confident that they understood its potential disadvantages and to be able to make a balanced judgement. As a consequence, researchers needed to be honest with them regarding the potential pitfalls.

> *"It's not within our experience really, is it, to think about things at that level?"* ***Female, Swansea***

In spite of these concerns participants still felt that nanotechnology had great potential and that there was not necessarily a need for all end users to understand the intricacies of the technology.

> *I don't think it is important to know about it in the depth… at the end of the day I think one needs to be oblivious to these things but understand that there could be applications behind it… it's got to be seamless to the end user… I don't think you [end user] need to know the granular detail behind it"* ***Male, London***

Risks and governance

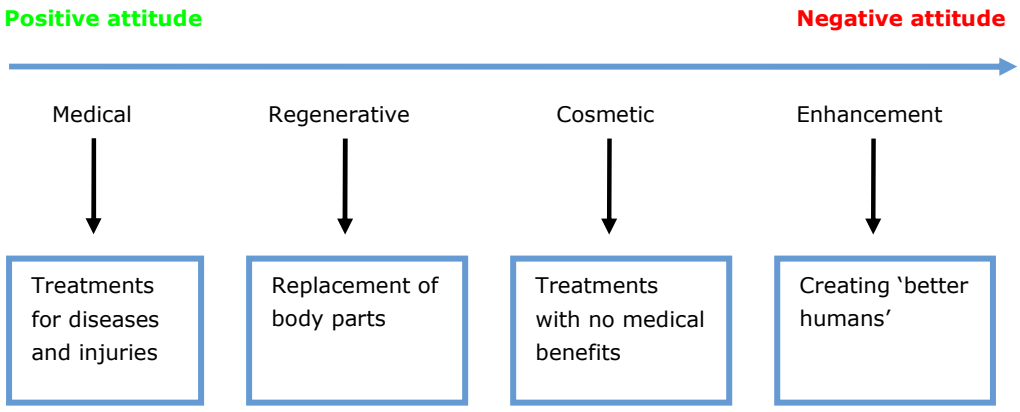
Participants stated they assumed that nanotechnology applications, treatments and medicines would have been tested thoroughly before being made available through the health system or more widely through the marketplace. Participants expressed surprise around the level of uncertainty concerning the toxicity and long term environmental impacts of nanotechnologies – given the number of nano-enabled products already on the market.

> *"I think the timescale is quite different. The long term effect on […] the environment […] can be measured in decades if not centuries, compared with the discovery cycle which can be quite[…]. So you have got this different, how do you measure 100 years of crop rotation for something that has taken five years to develop, you know"* ***Male, London***

Much of the concern expressed by participants centred on whose agenda was being served by the development of these products and that the over-riding concern could be for increased profits within private companies. It is unsurprising, therefore, that participants viewed scientists that work within universities as less likely to be driven by profit and were considered more trustworthy.

Medical, regenerative, cosmetic and enhancement applications

Participants became increasingly uncomfortable regarding applications driven by less by societal and medical needs and more by cosmetic and self interest.



At one end of the scale, the use of nanotechnology to treat common diseases was felt to be the most effective use – this specifically focused on 'quick win' technologies that could progress the treatment of diseases in a relatively short timescale. Whilst participants were also positive about applications that could improve people's quality of life through regeneration of their body, there was only a consensus on this for as long as the treatment returned the body to a normal state. Such applications were also viewed as a long way off.

However, participants were not keen to see the technology used in order to improve human abilities, were negative regarding issues of transhumanism and very negative in relation to military applications for the technology.

> *"[…]security and military technology[...] you can look at it in terms of how good it can be for health care, but it can also be used for bad as well, in terms of what terrorists can do with it and how they can develop it for their needs"* ***Female, Swansea***

> *"There will be a problem if we are all using that implant to be super humans, where does it stop? Or why can you have it and I can't have it?"* ***Female, London***

Regulating nanotechnology

There was some concern that as the momentum of and investment in nanotechnology increased it would be harder to stop if the application was having a negative social impact. Therefore participants agreed that there needed to be appropriate regulation and many expressed surprise that a regulatory body specifically to govern nanotechnology did not already exist.

"Well, I'm surprised that there isn't a regulatory body to be quite honest with you, made up of people from this group, where they are all having an input on this subject. Is that not what is happening?" ***Female, Swansea***

Without specific regulation – not only could health and safety issues be missed, some of the broader societal consequences of such a disruptive technology could be overlooked: the use of medical information, for instance.

2.3 Visions of nanotechnology

As part of the workshop, participants were presented with different 'visions' for the future of nanotechnology from three perspectives: scientific, social scientific and industrial. Participants were then asked to comment on the experts' visions for the future of nanotechnology.

2.3.1 Vision 1 – The scientist

The scientific vision brought forward the potential for nanotechnology to open up possibilities for developing new medicines and therapies, providing a revolution in medical care. The vision was that nanotechnology would help make diagnosis of diseases more sensitive, quicker and make diagnosis tools easier to use, allowing doctors to identify disease earlier and begin treatment sooner. It would provide the ability for people to test themselves and their health to be constantly monitored. Additionally, medical implants could take advantage of the improved knowledge on how materials like plastics and metals interact with the human body, allowing doctors to replace worn out body parts with artificial ones.

Hope not hype

To an extent participants agreed with this aspirations of this vision, believing that faster and more accessible diagnosis, less visits to the doctor and the ability to replace worn out body parts, all had the potential to significantly improve overall health and quality of life. However, participants were suspicious that the technology could not actually achieve all that it was purported to be capable of and that results would not live up to the hype.

Tied to this, certain groups were also worried that professional scientists tended to be concerned with achieving research goals rather than carefully thinking through the societal implications of their work. There were a range of contexts in which this was discussed, for instance in thinking through the wider impacts of aspects of regenerative medicine.

Again, participants were also concerned in whose interest the advancements in technology would serve and how these individuals and organisations were governed. They were not sure how nanotechnology was being guided and once

again expressed apprehension about its regulation. However, whilst participants were sometimes critical of the scientific vision, most agreed that the technology had the potential to offer significant benefits.

> *"I think it's very exciting, the possibilities, and I think that's why any scientist that's involved in that would be excited, because they've got the knowledge and understanding of the possibilities"*
>
> ***Female, Glasgow***

2.3.2 Vision 2 – The social scientist

The social science vision built on these themes by raising concerns about the potential for scientists' excitement relating to nanoscience to blind them from the social aspects of the technology. Nanotechnology was positioned as a science centred technology that claimed to improve lives, bodies, environment and the economy. Whilst the vision did not state that nanoscience would not lead to medical advances, it did express concern that all future applications needed to come with a health warning.

Concerns centred on the idea that scientists would become blinded by their own curiosity, without realising the complexity of the world within which these technologies have to function, and the potential consequences this would have for society – for instance the effects of having so much information about our medical conditions and possible future medical prospects.

Additionally, there were questions relating to the privacy of information generated by diagnostic devices, given that no system is completely secure. The social science vision also expressed concern that individually difficult solutions to medical problems, such as preventative medicine, including diet and exercise, were being overlooked in favour of technological quick fixes.

We need cautious development

Whilst this vision was believed to heed appropriate caveats for nanotechnology, overall there was a concern that it was too bleak a view to realise the prospects of the science. Participants wanted to see the benefits that technologies can bring, whilst being mindful of these issues through a more cautious development.

> *"We need to slow down. We're not computers. We can go fast with technology but when it comes to anything medical lets just slow down and go through the process. When things move too fast then mistakes are made"*
>
> ***Female, Glasgow***

Society needs to take some calculated risks

Overall, there was a view that there were inherent risks involved in developing new technologies and that if we were too careful with the development of nanotechnology then this could lead to the field stagnating and losing impetus.

Certain participant's advocated the market and our role as consumers as the best mechanism to develop nanotechnologies, and that individuals just needed to be well informed to exercise their choices well.

Others were more concerned about the impact of individual choices on wider society – citing the affects of previous technologies on moral choices (such as using embryos for research), social relationships (the use of information and communication technologies) and the natural world (the consequences of industrial pollution).

Privacy

Participants were also concerned about how privacy will be protected and to whom data collected about them would be made available. People were concerned that without proper regulation that the data could be made available to a wide range of organisations potentially creating problems for some people in getting health insurance.

> *"And if you know that information are you obliged to disclose that to employers, and is it shared with insurance companies? You might not be able to get any insurance"* ***Female, Sheffield***

In addition to this, some participants were worried about affordability of the new treatments and how this could lead to those with the ability to pay having access to new treatments, whilst those without such means would have to rely on cheaper treatments, creating a health elite.

> *"I think you'd still get the post-code lottery type situation that we've got now. The benefits should be for everybody regardless"*
>
> ***Male, Sheffield***

2.3.3 Vision 3 – The pharmaceutical company representative

The industry vision stated that whilst nanotechnology was potentially important in identifying diseases and developing therapies, the pharmaceutical industry's priority is to speed up the process of developing drugs, not to pursue pure research. Therefore the industry would like to see the government and universities spend their money wisely by placing more emphasis on considering the practical applications for nanoscience and the training of new scientists.

They would also like to see a strong international regulatory framework for nanoscience, but that this must be proportionate in order not to stifle its development. This framework will need to consider how nanoscience will blur the boundaries between medical implants, therapeutic drugs, and diagnostic tests.

Purposeful outcomes, positive regulation

Participants agreed with much of what was stated in the third vision and reacted positively to the potential for nanoscience to speed up drug development and deliver new, more tailored therapies. There was also agreement that nanoscience needed to be internationally regulated and several participants once again expressed surprise that there was not already a national or international regulatory body. A positive regulatory framework would help business as well as end users by ensuring that new treatments and therapies were safe to use and have not been rushed to market.

> *"Safety is paramount"* **Female, London**

Good regulation was seen as good for business. Nanotechnology has the potential to be a huge market and business will want to comply with regulation to access the market as long as these regulations are not overly restrictive.

> *"Europe is a huge market for imported products, if you have to have regulations to protect the public, that has a knock on effect around the world… therefore we can actually set the rules of the game to a large extent"* **Male, London**

Profit for society not just big business

However, participants were more cynical about who was driving forward the agenda for nanoscience and the extent to which future development would concentrate on increasing profits for the pharmaceutical industry rather than benefiting society.

> *"I just feel [Government] is investing in science that is of value to the UK industry, "well what about the patient", I ask myself?"* **Male, London**

As such it was appropriate that funders of research, both in business and government, engage in a wider discussion regarding the social goals to which the technology is driven, rather than viewing regulation as the only means of mediating this relationship.

In summary

Nanotechnology was seen as having a significant potential to improve human heath and quality of life, but the speed at which the technology was developing and the lack of necessary checks and balances were concerns. Participants were surprised given the novel nature of the technology that greater resources had not been placed into understanding its effects on humans and the environment; and more specifically that a single regulatory body had not been set up to govern its use.

Participants realised that commercial forces shape technologies and, though concerned about the ends to which potential applications could be directed, felt that an overly risk adverse culture could stifle both innovation and prevent us from to realising the many benefits of the research. Taking account of the wider public value of nanotechnologies is thus essential. Overall, healthcare applications should focus on the serious medical conditions facing society; whilst mindful of how advances in one field can be applied to less noble applications.

2.4 Workshop 2 – Healthcare applications

The second workshop consisted of an in depth examination of six potential application areas for nanotechnology in healthcare. For each, public aspirations and concerns were reviewed both in terms of the technology in itself, but also in terms of its impact on wider society. Each is now explored.

2.5 Case study 1: Diagnosing Illness

This case study discussed 'lab on a chip' technologies and in particular highlighted the potential for improved diagnostics by nano-enabled devices. Specifically the case study highlighted:

- In vitro uses and analysis of biological markers
- The idea of a health MOT
- The early diagnosis of serious conditions
- Personalised check ups of individuals with an increased risk of certain diseases

Findings were as follows.

Early diagnosis a key principle for the public

The concept of "lab on a chip" technologies and an individual "health MOT" were generally well received and this was seen as a high priority area for research. Participants commented that early diagnosis can save lives, this was accompanied by a hope that the technology would help to reduce treatment costs in the longer term. A strong view was a preference for 'preventative' applications than purely 'curative' ones.

> *'It's going to save an awful lot of money on the Health Service in the sense that if you let things go on too far… you're clogging the Health Service and costing a lot of money, where if you can catch something early, it's the idea that prevention again is better than cure'*
>
> ***Male, Sheffield***

Detection empowers

One of the most important principles for participants was that early diagnosis could enable them to undertake lifestyle changes and manage a disease before it advanced. In this sense, nanotechnology enabled people to manage their own health more effectively – and empowered them to take control of their lives.

The idea of testing for multiple conditions at once was seen as efficient and a source of reassurance when included in a health check-up; this was sometimes accompanied by a caveat that such a device could be a source of anxiety to the "worried well".

> *'You're going to start taking tests every day, you cannot live like that'* ***Male, Glasgow***

Disease context and professional support is important

The technology was also seen as useful in the monitoring and treatment of chronic conditions. It should be noted that the context in which the technology would be used was seen as important; distinctions were made between the unsupervised diagnosis of minor conditions in the home; ongoing monitoring and management of chronic conditions such as diabetes; and the use of the technology to diagnose more serious or potentially even untreatable/terminal conditions. Each of these uses had specific consequences for the relationship between the patient and doctor, the divisions between lay knowledge and professional expertise, and the ability of the technology to either empower or undermine individual agency.

For instance, it was commonly felt that receiving a serious diagnosis without the supervision of a suitably qualified clinician to interpret the results could cause the patient extreme stress and anxiety, it was also pointed out that misinterpretation of results was potentially dangerous.

> *'I think it should be [tested] in a place where there is a qualified person there and if there is bad news then they can help talk you through it and have suggestions. Then you proceed with the treatment. But to be on your own and find out something horrendous and you have to wait, no, no'* ***Female, London***

As such, participants were anxious to maintain access to healthcare professionals and were resistant to the idea of using medical technology without professional guidance and reassurance. Participants envisaged this technology as being used to streamline the traditional GP or hospital visit or as a tool for medical staff visiting patients outside of a clinical setting.

Reliability is important

Another important area of discussion centred on the results generated by such a device. It will be important to demonstrate that the technology is proven and the results accurate and reliable.

> *I'd want to be convinced of how effective it was. You could either not detect something. Or you could be misdiagnosed and panic.*
>
> ***Male, London***

It was also raised that as a consequence of this application there will be a significant number of people for whom medical science can provide diagnosis but not cure.

Privacy a concern

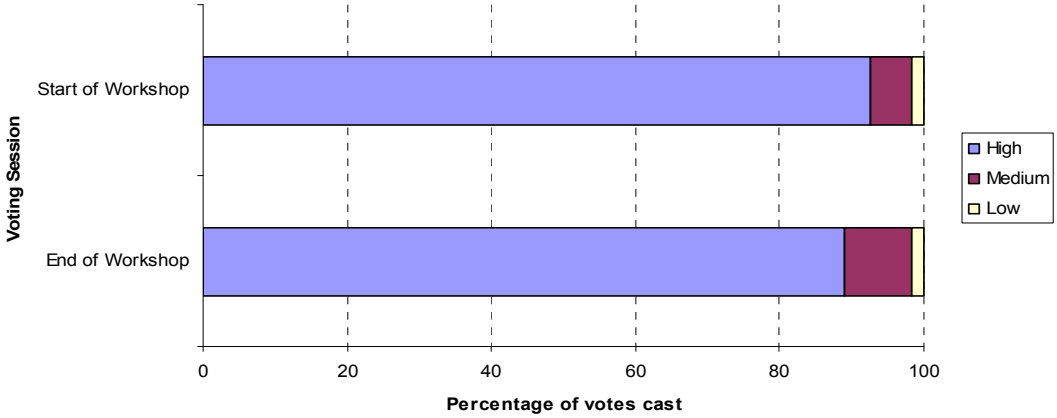
Such advanced diagnostics would provide a great deal of detailed medical information and undoubtedly prove extremely valuable to healthcare professionals. The data could potentially be collected by patients testing themselves at home and then transmitted electronically to an appropriate expert for analysis. An important consideration however, is the security and privacy of the data and the potential implications of a greater 'medicalisation' of public and private life. Specific concerns were often raised over access to information and the potential for discrimination from employers and service providers.

> *'There's that risk, the whole [insurance] industry could change. So you're going to end up without getting life insurance, therefore you can't get a mortgage'*
>
> ***Female, London***

Overall the most popular research application

In conclusion, this was the most popular research application – being viewed as a high priority by 9 in 10 participants. This was predominantly due to the prospective, enabling and empowering nature of the application. The research was also seen to build on existing UK expertise – which was valued. Concerns were focussed on setting acceptable limits in terms of how the technology was practically implemented and building in measures to ensure the privacy of medical data. With such limits in place the use of diagnostic nanotechnology is expected to save both lives and healthcare resources.

Figure 2: Prioritisation of diagnosing illness



2.6 Case study 2 – Infection control

This case study examined infection control and focused on the use of nanotechnologies to detect and eliminate pathogens on surfaces. Specifically the case study:

- Examined the potential for self cleaning surfaces
- Highlighted the fact that the impact of releasing nano-particles is largely unknown
- Highlighted the potential for these nano-particles to create a new generation of superbugs
- Explored the potential for preventing infections from spreading by employing better hygiene

Findings were as follows.

A key role in eliminating pathogens

Participants considered infection control to be an important area of research for nanotechnology. It was perceived to have the potential to address some of the key health issues of our time: from the control of superbugs such as MRSA to the detection of diseases such as Avian Influenza. MRSA was a particular concern for participants, with people put off going into hospital because of the fear of contracting a resistant disease. Nanotechnology could provide a quick win in the

fight against, not only the bugs themselves, but also the perception held by the public that the hospitals had no effective way of controlling them.

> *"We keep getting told. MRSA and hospitals, the majority of us are frightened to go to hospitals now because of what we hear"*
>
> ***Female, London***

Low-tech solutions

However, participants also stated that they thought that whilst nanotechnology had a role to play in controlling infection there were also low tech options that should be used in order to maximise the potential for a reduction in infection rates. For example, in hospitals, some resources could be diverted from R&D to simpler forms of infection control such as basic cleanliness.

> *"Bring back the matrons and you'd cut down a lot of this MRSA. Hygiene. Cleanliness. That is the first rule on the book"*
>
> ***Female, London***

These simple measures also have a part to play outside of hospitals in making sure that infections are reduced as much as possible, for example, in areas of food preparation. Several participants thought that advances in nanotechnology had the potential to make us lazier in our personal hygiene and some thought that hospitals should aim to go back to traditional methods for infection control.

> *"[Self cleaning surfaces] could make people careless about their own remedial cleaning… they may think 'I don't have to wash it or scrub it or tidy it up'"*
>
> ***Female, London***

> *"I think a lot of people would get lazy. They'd think surface spray or something like that that's got nanotechnology, it will clean it, so they don't need to clean it"*
>
> ***Male, London***

However, in areas where there was a particular risk of infection such as an operating theatre the use of nanotechnology to reduce infection should be treated as a priority along with the traditional methods. Self cleaning work surfaces were preferred to airborne delivery systems such as sprays.

> *"I don't want to live in a world where I've got to spray everything before I touch it. It's unnatural. What about all the spray, I've got to breathe that. I think we're looking in the wrong direction"*
>
> ***Male, Swansea***

The potential to increase infections

Participants were concerned that nanotechnology such as this could lead to more superbugs, as current infections were likely to become resistant - as has been the case with antibiotics.

> *"they [bugs] evolve at such a rapid rate. So prevent them from spreading rather than overcoming then. Because they're just going to go on. It's going to be a relentless struggle. Find something that will eliminate them and it's going to be a 'who is going to be first up the ladder' as such… just keep them out in the first place"*
>
> ***Female, Swansea***

Future risks

Participants also had concerns on the potential side effects of nanotechnology on the environment. Several participants felt that whilst there were potential benefits of nanotechnology - attention needed to be paid to any negative impacts that could affect our environment: particularly the potential to bio-accumulate in the food chain.

> *"If it is going back into plants, going back into the earth, where are we going with this? Are we all going to end up not producing fresh food?"*
>
> ***Female, London***

Participants were particularly apprehensive about the long term effects of this new technology and that such consequences will only be discovered after the technology has been in the field for a significant amount of time.

> *"It seems like it's equal on the scale. You could stop the MRSA but you don't know what the nano materials are going to cause in 5, 15, 20 years."*
>
> ***Female, London***

However, participants were equally keen to convey that these risks should not stifle research as there was so much to gain from potential applications. Instead, there should be a rigorous method for testing and an appropriate level of regulation to ensure that as products come to market, people can feel confident that the risks have been assessed appropriately.

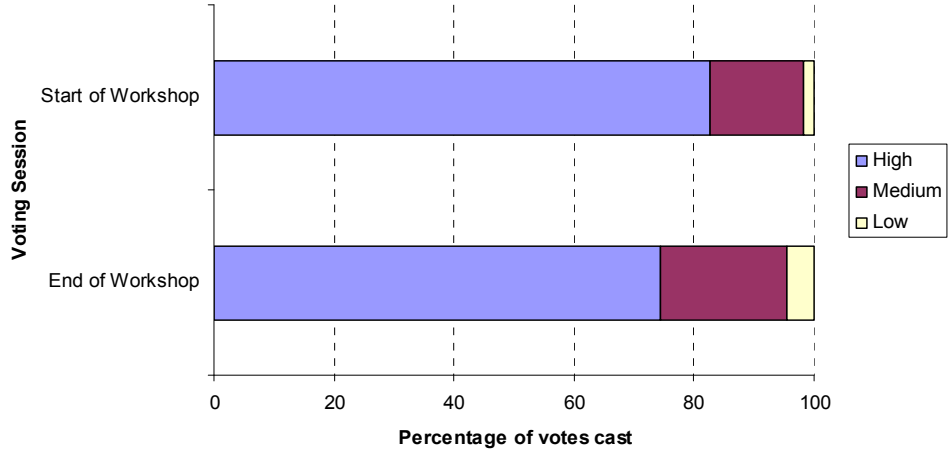
Bio-terrorism

Of all the applications for infection control, bioterrorism was the least discussed in the groups. Overall, whilst there was some concern regarding the potential for nanotechnology to be used as a weapon, participants felt that it could have an important role to play in helping to detect biological weapons.

Overall a high priority for investment

The over-arching consensus from participants was that, whilst they had some reservations about the long term safety of nanotechnology products, they had the potential to control infections such as MRSA and should therefore be considered a high priority for development. More than three-quarters of participants considered it a high priority, although this number decreased during the course of the workshop (see figure 3). However, participants thought that equal priority needed to be given to low-tech solutions, such as basic hygiene and cleanliness as it was important that people don't rely on technology as a magic bullet. Participants also had a preference for uses to be targeted in areas where risks of infections were highest, such as the operating theatre, rather than more liberal use in places like hospital wards.

Figure 3: Prioritisation of Infection Control



2.7 Case study 3 - Drug discovery

This case study examined drug discovery and focused on the use of nanotechnologies to enhance discovery process through the miniaturization, automation, speed and reliability of assays. Specifically the case study:

- Looked at the screening of new targets by examining how drugs work at the molecular level
- Examined the potential for personalised medicines, where drugs would be screened in relation to genotype
- Highlighted the time and cost of drug development and investment of the private sector

- Highlighted the relative role of nanotechnologies to other technologies in this area, particularly stem cells

Findings were as follows.

Benefits in efficiency, cost cutting and reducing side effects

The use of nanotechnologies for drug discovery was seen to have major benefits in terms of cost cutting and making the discovery process more efficient. Generally, participants were surprised with regard to both the time and the huge levels of investment needed to bring a new drug to market – and realised the cost of drugs were a significant expenditure for the NHS. In addition, certain groups noted that nanotechnology innovations in this area would increase the speed at which treatments were made available to patient. Disease specific drugs - particularly those where there were treatments which were currently ineffective - were also valued

> *If you can reduce the cost of testing and the time it takes to discover and these savings can be passed onto the health service and the consumer, it allows for the more efficient use of public funds.* ***Male, Swansea***

Reducing side effects was also greatly valued. This led to a wider discussion about the potential of personalised medicines. Whilst this principle was supported – and was seen to help build confidence in the safety of medicines - there were concerns around equality. This was expressed both in terms of the likely diseases that would be treated; and that the costs involved would mean that it would be hard to make treatments available through the NHS – potentially creating a two tier health system.

Finally, the potential for this application to cut down on the use of animals in research was viewed as a significant benefit. However, for certain groups, this benefit was questioned, particularly as the overall number of candidate drugs would be increased by any such innovation.

Concerns around who is set to profit…

The biggest concern related to this application was the issue of who was set to benefit from what was viewed as a large public investment in a private enterprise. Specifically, the majority of participants were concerned that R&D in this area should involve significant investment from pharmaceutical companies – as they were likely to financially benefit the most. Whilst it was acknowledged that investment in basic research was needed to develop the UK as a high tech economy, participants were sceptical with regard to how much money would

actually lead to tangible benefits, and saw innovation developed in the UK being exploited elsewhere.

> *Government funding is fine providing the benefit comes back to the public without companies making vast amounts of money out it.*
>
> ***Male, Swansea***

There were also concerns that the relatively low level of investment from an initiative such as the Grand Challenge would not be enough to make significant impact in this area.

…. and which diseases are targeted

In addition to economic considerations, a key issue for people was which diseases would be prioritised to receive attention from the innovation in this area. Given the commercial pressures within pharmaceutical companies, it was thought that these sorts of advances may lead to treatment of diseases associated with a western lifestyle – both serious conditions such as heart disease and more cosmetic concerns such as baldness. There was specific concern that investment in this area could not be directed towards particular diseases.

> *Do you tell them though what kind of areas they should be looking at, like say for example, a company comes to you and says right we want to look for a drug for Alzheimer's, that's what we're looking to develop, that's the area we want to work in. But somebody else comes and says oh no, we want to look at something that promotes hair growth and people are going bald, right. Obviously, well I would say an Alzheimer's drug's more important than something to make hair grow, so I would think any public money should go into more important things, rather than cosmetic things.*
>
> ***Female, Glasgow***

Overall ambivalence and uncertainty regarding this application

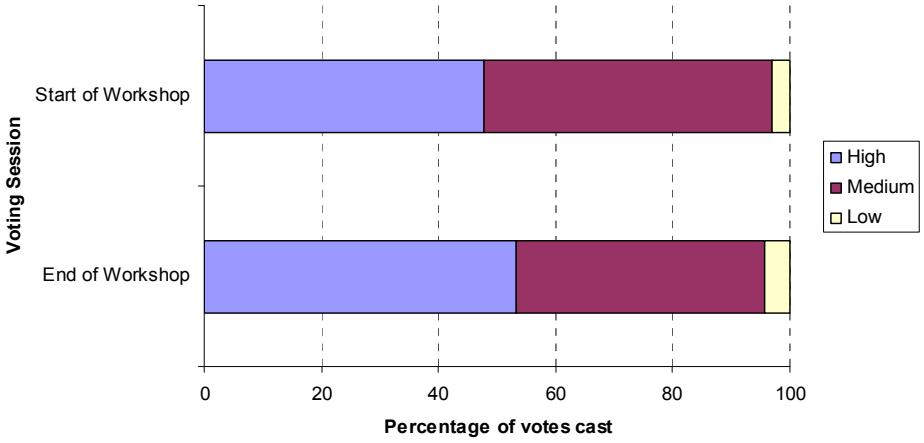
For many groups, drugs were seen as symptomatic of the strong focus in modern healthcare systems of treating the symptoms rather than helping to prevent diseases in the first instance. In this regard, for certain groups, this area was seen as less important than diagnostic applications – where the focus was on enabling people to take greater control of their lives and take preventative measures such as lifestyle changes.

However, other groups argued that the diagnosis of illnesses without the ability to treat them was a significant issue – and acknowledge the role of pharmaceutical drugs in both saving and improving life.

A medium priority – with public and private partnerships important for funding

Given this ambivalence, this area was seen as a priority by just over half of the participants (see figure 4 below). For any future funding in this area by EPSRC, it was argued that partnerships and joint investment should be developed with the private sector.

Figure 4: Prioritisation of Drug Discovery



2.8 Case study 4 - Regenerative medicine

This case study examined regenerative medicine and focused on the use of nanotechnologies to form scaffolds to support cells that can be implanted into the patient to replace diseased or damaged tissues. Specifically the case study:

- Examined applications that were near to treatment – such as growth of new cartilage and bone for implantation
- Examined longer term applications – such as replacement tissues for kidney, heart and brain.
- Highlighted uncertainties regarding how cell differentiate in vivo
- Highlighted uncertainties over the fate of nano scaffolds in the body

Findings were as follows.

Opportunity for improving peoples quality of life

Overall groups were very positive in relation to the potential of nanotechnology for regenerative medicine, though there was some scepticism expressed as to whether clinical applications could deliver in the long term.

In terms of positive uses, participants felt that applications in areas such as burns and skin ulcers were likely to make significant improvements to patient quality of life – these clinical 'quick wins' were valued by participants and seen as a priority for funding. More generally, applications for organ repair and the treatment of spinal injuries were seen as aspirations, which though potentially leading to huge advances, were unlikely to be brought to fruition though the funding of the programme.

There were many questions raised about the science and its potential applications – from overcoming tissue rejection issues to the safety of clinical procedures. It was concluded that major advances would be needed both in nano-engineering and stem cell research before these approaches could potentially benefit a range of conditions.

Concerns about side effects of Nano scaffold in body

The primary concern for this application was around the fate and re-absorption of nano-scaffolds in the body. There were particular concerns around safety and the potential for such treatments to precipitate other problems, such as cancer. In addition – there was acknowledgement that it would be difficult for science to establish exactly what the toxicological effects of such treatments would be.

> *Well I'd say I'd be worried about the two points I mentioned about the effects of re-absorption and the possibility of causing cancer by the differentiation of cells, if they didn't differentiate into the key targeted cell or tissue.* ***Male, London***

> *There's no way of really knowing how the nano particles will contact with the rest of all the cells and different proteins and different parts of your body. It going take some serious research into toxicology.* ***Female, Swansea***

The origin of the nano materials was also a concern for participants – with the use of natural materials such as collagen and hyaluronic acids helping to alleviate concerns for certain groups.

Related to these uncertainties, people felt that the use of nano applications in clinical trials was dependent on the disease context and the need for informed consent.

> *If you have a health problem, it would improve your quality of life or even extend your quality of life, you would want to take the risk, surely. It comes down to choice, doesn't it.* ***Male, London***

Specifically, given that this application offered the potential for therapies that are markedly different from existing treatments in terms of their clinical effectiveness, overall the risks were seen as manageable for serious and life threatening conditions.

Wider applications of the science a concern

There was a concern expressed in certain groups around the potential for this application to be used for cosmetic uses and more broadly for human enhancement rather than disease treatment. Both physical and cognitive enhancements were identified as areas where regenerative medicines could be employed. These were discussed both in relation to people wanting to stop the aging processes but also around the potential for technology to develop better humans.

> ***Male*** *It seems that you were raising some really tough moral questions, it might seem a tremendously good thing when we say well it repairs organs, but you know, there are limits, and there is this question about how far we should go.*

> ***Male*** *I think it depends which organ you're talking about. If you mend a kidney[…] it's going to let you live a normal life and that's the end of it, you know, you've repaired your kidney. Now if we're we're talking about the brain, if we start interfering with that and make superhumans, you know, make it a lot bigger, then we are in a problem.* ***Sheffield Group***

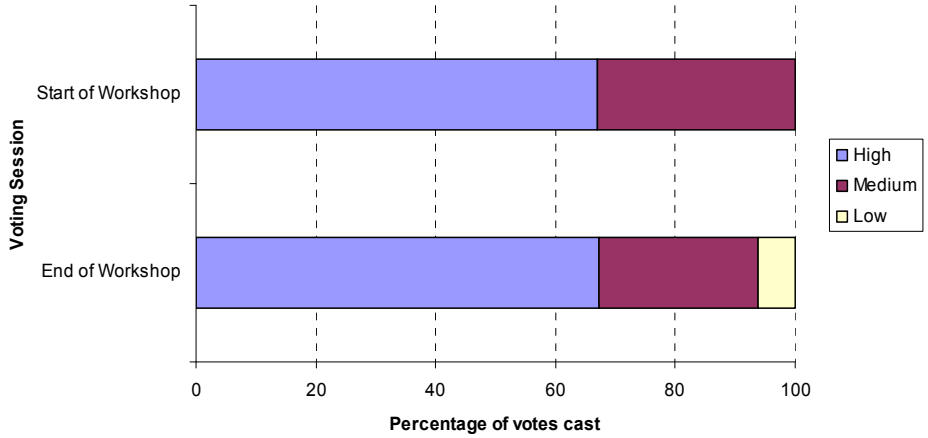
Overall the technology should not enable the rich to play god – but rather be available for the treatment of serious diseases affecting us all. However, the ability of the government or other agencies to direct and control nanotechnology to this end was seriously questioned.

Overall a promising area – but not without significant risks

While overall investment in this area was seen as a high priority by two-thirds of the participants, the potential side effects and the distance of some applications to clinical trial, meant that people were cautious around the benefits of investment in this area. Any funding would need to be strategically linked to

developments in other areas such as stem cell research for it to deliver on its promise.

Figure 5: Prioritisation of Regenerative Medicine



2.9 Case study 5 - Drug delivery

This case study examined the potential of nanotechnology to enhance drug delivery – and get small doses of drugs to difficult areas of the body. Specifically the case study examined the:

- Delivery or highly toxic drugs (such as anti-cancers) to specific targets to minimise side effects
- Delivery of new classes of drugs such as biologics
- Delivery drugs to organises and tissues that are hard to reach – such as crossing the blood – brain barrier

Findings were as follows.

Benefits in targeted drug delivery

There was a great deal of hope for this application expressed by the groups. The primary benefit was the potential to specify sites of drug delivery – particularly the move away from general chemotherapy approaches for treating cancer: it *cures what needs to be cured* – as one participant noted. While this was valued not only for significant benefits for patient well being, through the reduction of side effects, it was also noted that there were potential costs savings for the NHS.

Delivery to hard to reach tissues and organs was also thought to be a valuable application, though the discussion of biologics did not capture people's imagination.

Concerns about the reliability of the technology

While participants were optimistic about the use of nanotechnology for drug delivery, there were significant concerns as to whether such devices could actually live up to the claim of being site specific.

> *I think it's a good thing if it does target the area. If you can guarantee, I know it's going to be hard, but if you can guarantee it's going to get to that particular area and not affect the rest of your body.*
>
> ***Female, Glasgow***

There were also concerns about the mechanical effectiveness of such a small device – and the potential for it either to malfunction or be damaged and deliver the wrong dosage of medicine.

> *Is there going to be a risk of it getting out of there if that leaked and the whole amount of drugs goes into you for the year.*
>
> ***Male, Sheffield***

More broadly, there was concern that the technology would not be available for some time – or that it would be too expensive to be made readily available on the NHS.

Concerns about the safety and persistence of small invasive devises

There were large concerns for the majority of groups concerning the fate of implanted nanotechnology and the difficulties of recovering it. Many groups questioned whether the device would disintegrate in the body or whether it would be with you for life.

As a consequence, there were significant expectations that applications would have been rigorously tested before use in clinical settings. However, given the current level of knowledge on toxicity, certain groups had concerns as to the safety of the technology.

Individual control important

There were additional concerns as to whether this application empowered people to manage diseases that affect them. Specifically, these concerns related to an

individuals control over how and when to take medicines – and the fact that having an implant was a significant and long term choice.

> *If I'm taking a tablet I can read about it and know what it's going to do, it's my decision whether I take it. I know it's your decision whether you have an implant, but I wouldn't feel as much in control.* **Female, Sheffield**

More broadly, certain participants were unconformable with the idea of having a small device inserted in them – potentially because of privacy issues it precipitated. The key issue here was the intelligence of the device – for instance, people saw things like pacemakers as being a qualitatively different medical technology.

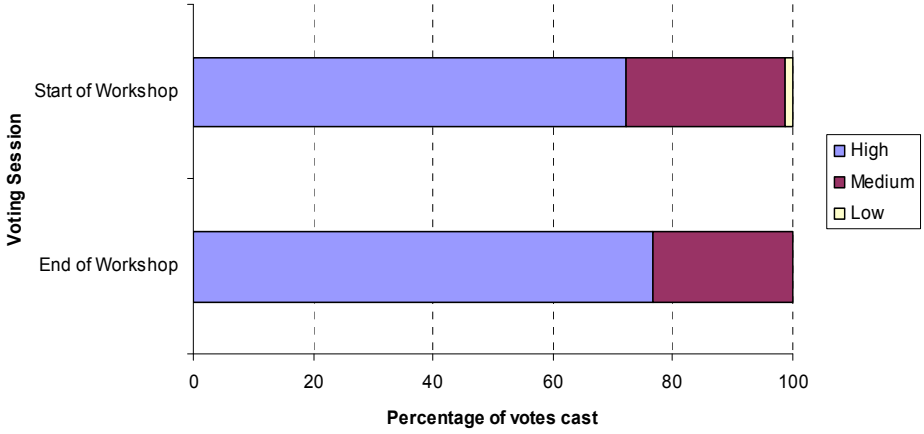
> **Female** *No the only negativity is purely personal one I suppose, the thought of having a chip in me regardless of what it is doing to me, I find quite uncomfortable*
>
> **Male** *People wear pacemakers*
>
> **Female** *Yes, yes, I hear what you are saying there, but this is, a pace maker is just a pulse isn't it? I have visions of people going around with a gun, you know, a sensor for chips. Having seen a very close friend of mine recently going through breast cancer, going through this dreadful nausea and losing her hair and everything else, it is, I am sure, she would have wanted to go down this avenue. I can understand it, there is a huge amount of positivity [around this application] when but my personal thought of having chips in us all, I just don't like.* **London group**

Overall a high priority for the treatment of serious conditions

Despite these reservations, the use of nanotechnology for drug delivery was a priority for investment – with over three quarters of participants believing it to be a high priority (see figure 6 below). Only diagnosing illness was ranked higher.

This level of support was particular due to the potential to treat very serious illnesses more effectively - as the risk/benefit trade off for the patient was seen to be acceptable. The research was seen to build on existing UK expertise – which was valued. However, much would be need to be demonstrated around the safety, reliability and scope of the devices. This is a significant caveat that would need to be addressed before more routine clinical use.

Figure 6: Prioritisation of Improved Drug Delivery



2.10 Case Study 6 - Theranostics

This final case study examined theranostics – and the potential to develop nano-enabled devices that combine both the diagnosis of a disease and the delivery of a therapeutic agent in a single system. Specifically the case study examined:

- Miniaturised diagnostic and therapeutic systems are implantable in the body
- Systems that were responsive to the environment
- Toxicity and fate of such devises
- The focus on a single disease or broad therapeutic principles

Findings were as follows.

Only limited benefits seen for this application

Theranostics, particularly nano enabled devices responsive to wider environmental signals, were viewed as the most controversial of all the applications – and triggered the greatest number of questions.

On the one hand, participants could see the benefits of an integrated system in terms of an efficient and easy way to manage a disease. On the other, and building upon views that had been expressed in the previous discussion around drug delivery, the very fact of having such an advanced and intelligent device inserted into the body made many people uneasy.

In terms of benefits, certain participants noted that for certain groups of people who had difficulty in taking medicines – the young and the elderly or infirm for instance - such a device could be helpful.

> *My granddaughter's diabetic, has been since she was 6 months old. Getting her to take her insulin jab can be extremely difficult. This could be excellent.* ***Female, London***

> *I was thinking about earlier when we was talking was one of the illnesses that people have a problem with taking medication is like people who have serious mental health problems. Would this be used for that type of thing? Because I think that would be a real boon for that.* ***Male, Glasgow***

More broadly, there was a pragmatic view expressed that, providing the devices were safe, it was better to have an integrated system, rather than a device that diagnosed a condition and a further device that released the drug.

> *If everything was proved, you know, beyond a shadow of a doubt, there is no point in having the one without the other, you may as well go for the whole shebang, have your diagnostic and your therapies at the same time.* ***Male, London***

Where positive applications of theranostics were viewed, they related to serious diseases like cancer.

Lack of control key

For the majority of participants, however, such devices disempowered people from taking control of their lives and their health

> *This technology is so clever, so small, that the person being treated feels like they don't have any direct control over their own health.*
>
> ***Female, Swansea***

Specifically, people wanted choices presented to them when health problems were encountered, and to be informed about those choices. People wanted to know what the diagnosis was and whether or not to make a particular treatment – rather than having this decision process automated.

Responsibilities for managing chronic conditions

Diabetes was discussed a great deal during the session as a potential candidate disease for this type of intervention. However, many thought that the existing ways of managing this illness were preferable to some of the risks involved in implanting a theranostic device.

Related to this, for some chronic conditions, certain participants argued that facing up to the responsibility of managing the disease was part of the personal responsibility of growing up and being an adult.

> *From an early age you've got to be responsible for your own treatment. She will learn and deal with it herself and she's got to learn to do that as she becomes independent. That's got to be a part of her life really. And if you've got something inside you you've not taken that responsibility.* ***Female, London***

A host of questions around the safety of theranostics…

More generally, participants had a host of questions about the safety and effectiveness of the technology. This included concerns around:

- what would happen if you are allergic to the medicine once the device was in your body;
- how many devices you would need – and whether you would need a large number to treat different diseases;
- whether something so small could work effectively
- Whether such devices would provoke immune response issues
- What happens when it runs out of drugs
- The fate of the device and whether it could be retrieved

… and their potential for misuse

Tied to these questions were concerns around the misuse of theranostic applications – for things like human enhancement, cosmetic uses (for instance for slimming) or for performance enhancement in sports. Certain groups also noted the potential for the device to be used for to help change people moods or even for recreational drugs. The use of such devices in the military was also discussed.

This led to a wider discussion that applications that have a reasonable potential for misuse should be not be funded through the public purse without strategies in place to deal with this:

> ***Male*** *People are going to get their hands on it that shouldn't.*
> *Q* *ARE YOU HAPPY IF THAT DOES HAPPEN*

Male *It happens with everything*

Male *Yes it will happen but you should regulate it.*

Male *But then it seems the key point then is where do you put your funding because if technologies are going to get out there and to be used for purposes other than which the were intended there is still the fundamental question as to what technology should we be putting our money in? So start with hence I think this process so*

Male *Well yes*

Male *The government through the Research Council has to make choices as to where to prioritise funding and probably when decisions are made there's probably little regard to the different uses to which the technology could be put, although that is changing to some extent. But from what you're saying that should be a consideration.*

Male *It's got to be a consideration. As I say, I can't see you stopping the technology really being developed, but as you say, is it whether the government should fund and it.*

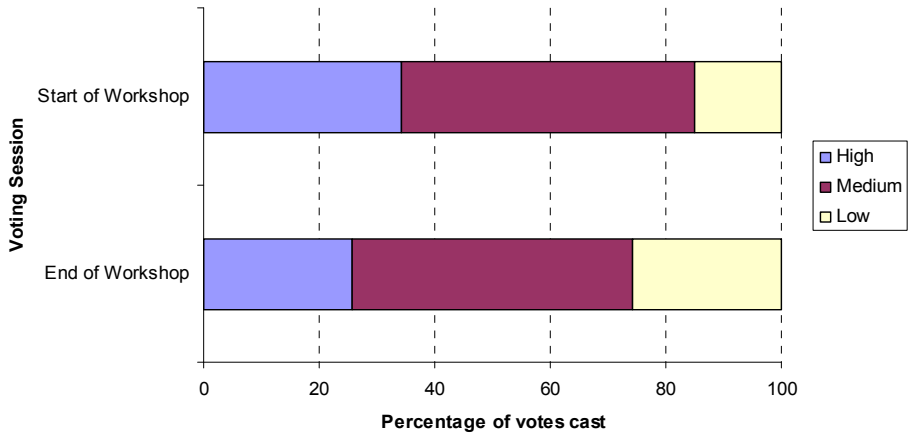
Male *I feel with this own though it's like trying to run before they've walked.*

Sheffield group

Given the potential risk – a low priority

In light of these discussions, though predominately due to concerns around the lack on individual control and safety, theranostics were voted as the lowest priority for funding of all the applications – being seen as a priority for a quarter of participants.

Figure 7: Prioritisation of Theranostics



In summary

All of the potential healthcare uses of nanotechnologies showed promise, though the risks involved in certain applications outweighed the gains. Technologies were preferred where they empowered people to take control of their health, where they tackled major diseases for which there were ineffective current treatments, where they reduced side effects, made costs savings and built on existing UK strengths. They were less favoured where they had potential for misuse, had negative health or environmental impacts, and, in particular, when they were invasive applications that were very intelligent. The table below summarises the aspirations and concerns for all six applications.

Table 2: Summary of findings in six application areas

Application	Aspirations	Concerns	Rank
Diagnosing Illness	Early diagnosis Preventative medicine The need for professional advice Information that enabled people to make changes	Misdiagnosis Reliability Diagnosis without treatment Worried Well Privacy	1
Infection control	Tackles an important issue from public perspective Treats illness contracted through no fault of own Combating bioterrorism	Low tech solution may be more effective Could create superbugs Living in sterile environment Kills good bugs too Wide environmental impact	3
Drug discovery	Could reduce side effects Efficient Saves money	Who benefits Which diseases treated Appropriate use for pubic purse	5
Regenerative medicine	Near term applications Improve quality of life Longer term benefits in treating range of tissues/ organs Builds on existing UK strengths	Toxicity Fate Human enhancement	4
Drug Delivery	Treating serious diseases like cancers Target specific and reduce side effects Builds on existing UK strengths	Safety Reliability Control Persistence and fate Misuse	2
Theranostics	Helpful to certain groups in society – young, elderly and infirm Could treat some serious diseases	Disempowering Devices 'too intelligent' Misuse Safety Not retrievable Persistence and fate	6

3 Conclusions

Overview

There were a wide range of issues discussed in the groups which provide insight into the public's priorities and concerns for potential applications of nanotechnology for healthcare.

Some of these issues are specific to nanotechnologies – others relate to the governance of science and technology in more general terms. Addressing them will not only require thought by researchers working on the development of these technologies, it will also require wider institutional action and co-ordination.

EPSRC has a key role to play – and the development funding programmes such as the Nanotechnology for Healthcare Grand Challenge call which begins to take account of wider values in the development of nanotechnology is valuable and was welcomed by public participants. More broadly, there are a number of issues beyond the scope of the call and the role of the Research Councils more generally which will require other ways for institutions to consider and reflect on the trajectory of new and emerging technologies.

Key conclusions are described next.

Healthcare applications greatly valued

The use of nanotechnology for applications in healthcare, as opposed to other social and commercial applications, was greatly valued by participants. There was a great deal of hope that the funding of research through the Grand Challenge could provide resources to make a major impact of the people quality of life, particularly through the early detection of diseases and more effective drug delivery. Though all applications were seen to have significant benefits, those which treated serious illnesses such as cancers and heart disease, together with more headline conditions such as MRSA, were prioritised. Participants were also keen for funding to focus on building existing strengths in UK academia, such as links into stem cell research.

Equity, empowerment and empathy important

When considering the applications, a number of factors emerged regarding how those developing the technology should account for societal issues. These included the importance of equity and developing treatments that are available for the many and not just the few; applications which could help provide long term financial savings for healthcare; and those which enabled people to take control of their lives and the diseases that affect them.

This last point in particular was a one of the key principles governing peoples' views on nanotechnology. Devices that promote patient control and agency were fundamental to the types of technology that participants wanted to see developed. This was tied strongly to the view of prevention being better than cure – diagnostics applications were strongly prioritised for this reason. More intelligent systems – such as theranostics - which for participants reduced the role of the patient to a bystander in their own illness, were less well received.

More broadly, understanding patient need and having empathy with the personal impact of healthcare technologies on peoples' lives – for instance in terms of the emotional significance of being diagnosed with a condition - should be paramount in researchers' minds.

To begin to address these, healthcare applications for nanotechnology could begin to actively engage patients in their development – helping to involve users in the co-creation of devices.

Safety and reliability major concerns

Almost all participants had major concerns around the safety and reliability of nanotechnology applications. Not only was this in terms of wider environmental consequences, for instance the potential of infection control applications to create superbugs and precipitate the build up of nano-particles in the environment. It was also specifically in terms of the physical and clinical effectiveness of devices. There was a strong expectation that technologies would not be able to live up to their claims - from the potential for misdiagnosis for in vitro health testing, to much greater concerns around the reliability, fate and toxicity of implanted nano-devices.

As a consequence of this, serious thought needs to be given to the scope nanotechnology applications in certain instances. For example, to minimise environmental pollution, use for infection control in hospitals could be restricted to certain areas, such as operating theatres, and certain applications - nano-surfaces rather than sprays. Other low tech solutions such as basic hygiene should be used in other areas.

For invasive devices, not only will rigorous testing be very important, consideration will need to be given as to how such devise can be recovered once they are in the body and how they may be externally controlled. Lack of ability to do this is likely to seriously compromise public confidence in the technology.

Tipping points a major concern for investment in nanotechnology

All participants were aware of the potential of any technology to have both benign and malignant applications. The consideration of these wider implications was

viewed to be a key role for funders when prioritising research – rather than just accepting it as an inevitable consequence of technical innovations.

For instance, a series of tipping points were described concerning the uses of nanotechnology for regenerative medicine. One of the key themes to emerge from this was that funding should focus on areas of research which will result in relatively near term clinical applications. The promise of regenerative medicine more broadly, for the treatment of major degenerative diseases, though a laudable goal, was viewed as a distant prospect and hence more appropriate for other forms of funding, such as responsive mode.

Wider social implications also arise from concerns around tipping points in regenerative medicine. Specifically, scientists should be mindful of the potential to improve on nature. While it was obviously expected that government (notwithstanding military applications) would not directly fund research on human enhancement, people were concerned that, in the general move to repair body parts, researchers could enhance the capability of those organs beyond their natural range.

Tipping points and societal implications were also highlighted in terms of the use of theranostic devices - which could be used for recreational purposes, mood and cognitive enhancement and performance enhancement.

It is notable that the two applications which were seen as having the most potential for misuse - regenerative medicine and theranostics - were among the lowest priorities for funding from the public perspective.

Whose agenda is being served?

Related to this was a concern of whose agenda is being served in the development of technologies – and in particular the role of the private sector in this area. Conclusions from these discussions are twofold.

First was not a concern of the role of business in driving nanotechnology per se, but rather that any source of government funding needs to take account of where benefits from translational research are likely to accrue and what are the appropriate levels of investment for other parties in certain research applications. The use of nanotechnology for drug discovery, a process almost exclusively undertaken by private sector organisations, was viewed as a relatively low priority in this regard. This is not because this area was deemed to be unimportant - but rather the belief that the public value and return on such an investment was viewed as inequitable.

Second was a greater concern around the societal ends to which innovations in the private sector would be directed. Given the levels of investment in nanotechnology by business, there was a strong belief that it would likely lead to

a variety of profitable cosmetic healthcare applications for nanotechnology. While there were mixed views as to the desirability of this, potential externalities - such as environmental pollution - strongly changed peoples perceptions of the trade off between risks and benefits for certain nanotechnology applications.

Put simply, people are less likely to tolerate the downsides of technical innovations when trying to find a cure for baldness than trying to find a cure for cancer. The success of nanotechnology applications in the private sector therefore have significant implications for the overall confidence in and social desirability of nanotechnology research more generally.

Regulation – rigorous but fair

As a consequence nanotechnology regulation is important. Participants were concerned both that specific regulations had not been developed for nanotechnology products for healthcare in the UK, and that there was a relative paucity of data on the long term effects of nanotechnology on human health and the environment.

It was strongly argued that regulations should not stifle innovation, and whilst needing to be rigorous, regulations should also be fair. International efforts to develop standards for regulation were also highlighted. As well as governing the health and safety implications of the manufacture and use nanotechnologies, regulations should also be mindful of the wider implications of technologies, such as privacy. It should be noted that participants did not argue for a moratorium on nanotechnology given these uncertainties.

Rather there was a concern that greater time and care should be taken to test nanotechnology applications for healthcare, ensuring that new treatments and therapies were safe to use and have not been rushed to market.

More broadly, participants acknowledged their lack of knowledge to make informed decisions around nanotechnology and, as such, were very much in the hand of regulators and scientists concerning how these interventions are directed and controlled.

Given the gaps in knowledge, this places a duty on scientists to engage with the public in an open and honest dialogue around risks and benefits, including areas where risks are not known or easily quantified. This would particularly include academic research scientists - who were viewed as more likely to be independent scientists and more trustworthy.

Clinical trials

When considering clinical trial applications, thought needs to be given not only to research ethics and the need for informed consent around those likely to be

enrolled in trials – but also the types of diseases that are likely to be prioritised to test devices in vivo. Cancers and other life threatening diseases were highlighted in this regard. Other less critical, though nonetheless serious diseases like diabetes, people considered to be less worth the risk – mainly due to the effectiveness of current forms of treatment and uncertainties around the fate of nano-devices in the body. Though certain participants argued it should be left to the discretion of the patient, researchers should be mindful of the allure and potential hype around any new medical device.

Funding principles

Finally, and drawing on the findings above, there are a series of tactical principles that may be of specific use in the research call. Specifically participants were more likely to be supportive of applications that:

- have a short-to medium term pay off – rather than long term/high risk return on an investment
- promote prevention rather than cure
- promote patient control and agency
- are affordable to healthcare systems
- are reliable
- target serious conditions
- can be recovered from the body
- build on strengths in UK expertise

As strongly expressed by participants - nanotechnology does have the potential to make a significant impact on healthcare. Its success will in part depend on how well it can account for these public aspirations and concerns.

Appendix 1: Topic guide for workshop 1: Visions for nanotechnology

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Nanotechnology Workshop 1:

Topic Guide

Time	Session and aims	Topic areas	Tools/Stimulus material
10.30-1045 Whole group	*Session 1: Welcome and introduction* Introduce study aims Canvass individual views and awareness on healthcare in general and nanotechnology in particular (for tracking)	Overview of study Warm up questions on general attitudes to S&T including issues of trust General questions on healthcare and nanotech research; priorities for areas of research	IML interactive voting **See annex 1 for Qs**
10.50 – 11.25 Breakout groups	*Session 2: My vision for medical technologies* Warm up group Understand peoples	Introduce participants to one another Ice breaker: what comes to mind when say the words medical technologies Views, aspirations and concerns or medical technologies?	

	unprompted aspirations for medical science, drivers in healthcare and awareness of nanotechnology	Probe: • Experiences of technologies • Diseases of particular concern (self/family/society) • Views on health inequalities • Preventative medicine, rather than just treating symptoms • Quality of life and age related diseases • Infection control – cleaning up hospital bugs • Early diagnosis of diseases and health monitoring • The use of medicines and drugs in society • Views on drug delivery, side effects, costs and time it take to make them • Personalised medicines Knowledge of nanotechnology previously? [link back to session 1] Knowledge of potential use of nanotechnology in healthcare	
11.30-12.15 Whole group	*Session 3: Introduction to nanotechnology* Provide people with a broad understanding of nanotechnology research in UK	To cover: What is nanotechnology research What are its potential applications and challenges What are the key drivers shaping nanotech research What are some of the environmental, health and safety issues facing nanotechnology/ ethical/ social issues What is the UK's international position in nanotechnology research	Presentation by a scientist and social scientist

		What is the UK investment in nanotechnology and what are the wider innovation and commercial issues How does the UK regulate research / comparison to other countries Q&A	
12.15-12.50 Whole group	*Session 4: Group discussion of presentation and handouts* Enable people to discuss and get up to speed with nanotechnology research and development in the UK	[Give handouts on nanotechnology] Take each in turn Reactions to nanotechnology research Reactions to applications Reactions to risks and regulation Reactions to commercial drivers	Slides summarising handouts Pictorial handouts summarising key findings, **see annex 2** Scientists and ethicist as a resource
12.50-1.25pm	Lunch		
1.30-2.25pm	*Session 5: Visions of nanotechnology for healthcare* Explore three different visions for nanotech research in healthcare	State vision handouts are fictitious. **Give out Dr Dave Morris's vision (vision 1):** (15 mins) Does the area resonate with their own views What opportunities are there:	Three handouts - each exploring different views on nano for healthcare, see annex 3 Discussion with scientists/ ethicist

	Explore views on opportunities to influence visions	What are the problems/ challenges and should these limit the research in some way or could they be overcome Probes: How do you feel about: • quick diagnostics • monitoring in home • implants • hype of the benefits of the science • government role in identifying risks (link back to previous session) **Give out Prof Mary McLeod vision (vision 2): (15 mins)** Does the area resonate with their own views What opportunities are there: What are the problems/ challenges and should these limit the research in some way or could they be overcome Probes: How to you feel about: • Risks given uncertainties • Knowledge of potential future diseases • Who has access to this information • Technical fixes to complex problems • Why we are doing this and in whose interests. • Which voices may be excluded from discussions on nanotechnology	

		Give out Rachel Foster vision (vision 3): (15 mins) Does the area resonate with their own views What opportunities are there: What are the problems/ challenges and should these limit the research in some way or could they be overcome Probes: How to you feel about: • Costs of drug development • Whether the needs and wants of uk industry deliver public benefit • Regulations being too stringent (nb is it right for someone with a disease to accept the risks of a treatment) • International standards (how do. should we compete with others with more permissive regimes) • High levels of investment to get into therapies Overall, reflecting on the visions and their own discussions (10 mins): • Who do you think will benefit from nanotechnology research in this area? • Who do they feel is controlling research? • Do they trust how the science	

		is being developed? • Do they feel nanotech research will be available and affordable? • What will/might the research mean for them and their family?	
2.30-2.45pm	*Session 6: Reflections on day* To understand which issues influenced views	What 3 things would you like to feedback to EPSRC about today? What has surprised you most about today? What things have influenced you? What would you like to know more about to make judgments about nanotechnology for healthcare	
2.45pm	Session 7: Feedback and voting To track impact of discussion on views To explain what happens next	Feedback on 3 key issues Prioritisation of research areas for next session and voting Thanks and next steps • Analysing the information • Preparing for W2 on 10 May • Look at applications in more depth Highlight where they can go for further info: Wellcome trust **http://www.wellcome.ac.uk/Professional-resources/Education-resources/Big-Picture/Nanoscience/index.htm** Science museum: **http://www.sciencemuseum.org.uk/antenna/nano/**	IML voting on key tracking questions, **see annex 4**

3.00pm	Ends		

Annex 1: IML Voting Questions

Q1: What gender are you?

- Male
- Female

Q2: What age group do you fall into?

- 16- 34
- 35-54
- 55+

I now want to ask you about some statements people have said about science. For each, tell me how much you agree or disagree.

Q3-8: Britain needs to develop its science to enhance its international competitiveness
Scientists seem to be trying new things without stopping to think about the risks
We depend to much on science and not enough on faith
I trust scientists to tell the truth
The media sensationalises science
Science is driven by business – at the end of the day it is all about money

- Agree strongly
- Agree
- Neither agree nor disagree
- Disagree
- Disagree strongly
- Don't know

Q9: How familiar are you with nanotechnology research?

- Very familiar
- Fairly familiar
- Not very familiar
- Not at all familiar

Which of the following areas do you think is high, medium or low priority for medical technologies spending?

Q10: Preventative medicine – where devices can be used to diagnose the potential onset of diseases at an early stage

- High priority
- Medium priority
- Low priority

Q11: Implants which can monitor a patient's health and release therapeutic agents such as drugs inside them

- High priority
- Medium priority
- Low priority

Q12: Infection control, where there is a focus on the fast detection and control of things like hospital bugs such as MRSA

- High priority
- Medium priority
- Low priority

Q13: Regenerative medicine, where there is a focus on helping the body to repair tissues that have been damaged though injury or diseases

- High priority
- Medium priority
- Low priority

Q14: New methods of drug discovery, to increase speed, effectiveness and cut down on the use of animal testing

- High priority
- Medium priority
- Low priority

Q15: Personalised medicines, where you test people's likely reaction to taking new medication and to tailor a treatment for them based on the test results

- High priority
- Medium priority
- Low priority

Q16: Better means of drug delivery, to reduce the side-effects, cut down on costs, and to target areas of the body which it is hard to get drugs to effectively, such as the brain.

- High priority
- Medium priority
- Low priority

Q17: And if you had to prioritise them, which would be your top 3 (press three numbers only)

1. Preventative medicine and early stage diagnostics
2. Implants to monitor diseases and realise drugs
3. Controlling bugs such as MRSA
4. Regenerative medicine – helping the body to repair tissues
5. Quicker ways for drug discovery
6. Personalised medicines – helping to tailor medicines and treatments for individuals
7. Drug delivery
8. None of these

Annex 2: Nanotechnology handout sheets

H1 What is nanoscience and nanotechnology?

Nanoscience is the science of the extremely small; one nanometre is a billionth of a metre or a millionth of a millimetre. To give an idea of scale, the diameter of a human hair is around 80,000nm.

Nanotechnology describes many diverse technologies and tools. One thing that all nanotechnologies share is the tiny dimensions that they operate on. They exploit the fact that, at this scale, materials can behave very differently from when they are in larger form. They can be more reactive, display different physical properties and interact with living things differently.

Nanoscience is concerned with understanding these characteristics and effects; nanotechnologies aim to exploit them to create new structures, devices and systems for a variety of different industries.

Nanotechnology is not as new as you might think; people have exploited the properties of nanoparticles for centuries. For example, Gold nanoparticles are responsible for some coloured pigments used in stained glass and ceramics as far back as the 10th century (depending on their size, gold particles can appear red, blue or gold).

H2 What are the potential applications of nanotechnology research?

Nanotechnologies have potential in areas as diverse as healthcare, energy storage, computers and communication systems, new materials, security & military technologies to name just a few.

Many nanotechnologies are already in use. Computer chips have nano-sized features etched into their surface, and nanotechnologies have enabled computers to be made smaller and faster over the last thirty years. More recently, researchers have produced nano-sized wires and tubes. Nanowires have remarkable optical, electronic and magnetic properties, so its hoped they will prove useful in storing computer data. Carbon nanotubes may lead to new building materials, being much stronger and lighter than steel. Nanoparticles of titanium dioxide have been added to some suntan lotions and cosmetics, as they can absorb and reflect UV rays.

In healthcare, nanotechnologies offer potential in areas such as targeted drug delivery, drug discovery, disease diagnostics, regenerative medicine and infection

control. We will be exploring some of these applications in more depth in the next workshop.

H3 How is nanotechnology research regulated and what are some of the risks?

Nanotechnologies span such a wide range of areas that no one regulatory body is responsible for the field as a whole. Rather, nanotechnologies are likely to impact on the work of many regulators and it will be important for them to understand the implications as the technologies develop.

At the moment there are no regulations **specific** to medicines or medical devices using nanotechnology and existing regulations may need to be modified to take account of nanoparticles special size-related properties. However, the Medicines and Healthcare products Regulatory Agency, which regulates this area in the UK, believes the existing regulations for medical devices and medicines are sufficiently broad in scope to cover risks associated with nanotechnology.

Research is still being developed to understand the environmental, health and safety risks associated with nanotechnology. It is known that nanoparticles may be able to penetrate human cells. However, there is no evidence that the limited number of nanoparticles used in cosmetics, for instance, can cause any damage. At present there is little research into the general toxicity of nanoparticles with respect to damage to DNA or lungs. Very little is known about the impacts of nanoparticles in the environment, including how they may accumulate in plants and animals.

H4 What are the commercial drivers for nanotechnology?

There is a good deal of hype surrounding nanotechnologies - which have been trumpeted as the 'new dot com', the 'new biotech', 'the new industrial revolution' and the 'greatest business opportunity of the century'.

While the reality is likely to be far less sexy, researchers have estimated that by 2008 the global demand for nanoscale materials, devices and tools will cross $28 billion and by 2014 the market for innovations sparked by various types of nanotechnology could reach
$2.6 trillion.

A recent inventory developed by the Project on Emerging Nanotechnologies in the US indicates that over 320 nanotechnology-enabled consumer products identified by companies from 15 Countries are presently on the market. Investment

advisors Innovest suggest there are actually 700 products containing fixed and free nanoparticles now available.

In 2005 alone, governments, companies and venture capitalists spent $9.6 billion on nanotechnology R&D worldwide, up 10% on 2004 with a regional breakdown. This isn't just a developed-world phenomenon: research is taking place in developing countries, with India, Brazil and China making major funding commitments.

Annex 3: Visions for Nanotechnology

Dr Dave Morris, Head of Nano Research, Oxbridge Institute

"In recent years we have seen fantastic advances in our ability to study and manipulate individual atoms and molecules. Advances in technologies that allow us to understand the basic structures of materials have led to an exciting new field of research called Nanoscience.

I feel really privileged to be working in nanoscience right now, it's like being an explorer stepping foot onto a vast new continent for the first time. The possibilities are limitless. One of the most exciting areas is to use the new understanding of atoms and molecules to radically change medical science.

I believe we can understand the physical interactions that are fundamental to all living things. And this opens up huge possibilities for developing new medicines and therapies. I truly believe that in my lifetime we could see a revolution in medical care.

Drugs can be targeted to only the parts of the body affected by disease – drastically reducing side effects. Nanoscience will also help make diagnosis of diseases more sensitive, quicker and easier to use. This will allow doctors to pick up signs of disease much earlier and therefore to begin treatment sooner, which could have a big impact on outcomes. Also, with easier diagnostic devices, people can test themselves, or even be constantly monitored in the comfort of their own home. And very soon medical implants will routinely take advantage of our improved knowledge of how materials like plastics and metals interact with the human body. This will allow doctors to replace more warn out body parts – helping people to live well for longer.

Underpinning all this potential is excellent science. I'm not saying we are there just yet, but if the scientific community gets the right level of financial support the possibilities are endless. The UK has world-class scientists working on biomedical problems, and we've got a first rate pharmaceutical industry. So the potential is there.

But so often in the past the government has failed to follow through on a strategic commitment to invest in basic science. It's vital to develop the underpinning scientific knowledge, also to train the skilled workforce we will need to take advantage of the potential of nanoscience.

I'm hugely excited about the future. Now of course there are risks, there always are when developing new medical technologies. It's the responsibility of the Government to coordinate research on risks, and make sure they are properly

regulated. But I'm just itching to get back to my lab, the science is so fascinating and the possibilities are endless.

Social scientist

Prof Mary McLeod, University of Ealing

The excitement about nanoscience that you hear about so much from scientists and government is just the latest in a long list of promises about how science-led technologies will make our lives easier, our bodies healthier, our environment cleaner and our economy more productive. Now I'm not saying that nanoscience won't lead to medical advances, I'm just saying that all the promises about future applications need to come with a health warning.

There are a few questions you should ask yourself before getting too carried away by the excitement of nanoscience. After all, we can all think of past cases were scientists have become blinded by their own curiosity and sense of excitement. When looking at the world as made up of atoms and molecules, sometimes scientists believe that everything can be controlled, without realising the complexity of the world in which all technologies have to function.
Here are a few points to think about. If these new nanomaterials are going to have such a powerful effect on the human body, how do we know from the outset that there won't be any unintended consequences? How should we balance future possibilities for health benefits with future possibilities of environmental or health risks?

One area where I expect we will see some big questions is in new diagnostic devices. The benefits are tantalising – imagine being able to go to your GP and being tested right there and then for a whole range of conditions – and getting answers back instantaneously! But there are problems as well. Given that no system is ever completely secure, what are the consequences of having so much information about our medical condition, and possible future medical prospects? How will privacy be protected? And will we see a greater 'medicalisation' of life – where we become increasing defined by our medical conditions and future health risks? Do we really want all this information and will we always be able to do something about what we find out?

The trouble about getting swept up in the excitement of the latest technological breakthrough, is that some of the more complex solutions to medical problems get overlooked. Questions of preventative medicine, including the wide environmental causes of disease, diet, including how food is grown and manufactured, and exercise –as well as the underlying inequalities in society that we know give rise to health problems. These social dimensions may seem complicated when compared to a 'technological fix' but we know that there are unglamorous methods that work in tackling them – such as providing support for older people to avoid falls. Such everyday solutions can have a huge impact on quality of life. We have to ask broader questions about why are we doing this; whose interests; what are we missing?

Rachel Foster, Pharmaceutical executive, Pieagra Plc
Nanoscience is certainly a potentially important area of science for us in the pharmaceutical industry. We are looking to nanoscience to help identify new ways of identifying diseases and developing therapies. But crucially, a priority for us is speeding up the time it takes to develop a drug from the research bench to use in the patient. The work of researching and developing new drugs is a long and complex. On average is takes well over 10 years and £550 million to develop a new drug – so you can imagine that we will look to any advances for help in speeding up the drug discovery process.

We in the pharmaceutical industry don't just look to nanotechnology. As the biggest business investor in research and development in the UK, we are constantly looking to new ways to develop medicines. The big question for us is how will the best ideas developed in the Universities make it to the 'real world' of industry? We want the government and universities to place a much bigger emphasis on scientific research that will provide useful knowledge to industry, and training scientists who will come and work for us.

Regulation – we want to see strong regulatory framework. But it must be proportionate, in other words the regulatory burdens should not be so great that potentially important new drugs are not developed. I would say that there are two important issues for regulation of medical nanotechnology. The first is that we need to see international standards. The pharmaceutical industry is truly global, and we want there to be harmonisation of regulation – not different countries going in different directions regarding nanotechnology.

A second question for regulation is how to cope with a potential blurring of boundaries between medical implants, therapeutic drugs, and diagnostic tests. These have until now been regulated separately, but nanotechnology could change this. One can imagine a device implanted into your body that will constantly monitoring your health and automatically deliver the required drug dosage according to specific signals from the body. For example, using this approach it might be possible for people at risk of heart disease to maintain the right concentration in their body of the drug needed to lower cholesterol.
It's all well and good to come up with bright ideas, but if its going to make a difference to people's lives, we need to make a workable product. It's therefore of crucial importance that the government spends its research money wisely, by making sure that it is investing in areas of science that are of value to UK industry.

Annex 4: Repeat IML Qs and feedback

Q18-23: Britain needs to develop its science to enhance its international competitiveness
Scientists seem to be trying new things without stopping to think about the risks
We depend to much on science and not enough on faith
I trust scientists to tell the truth
The media sensationalises science
Science is driven by business – at the end of the day it is all about money

- Agree strongly
- Agree
- Neither agree nor disagree
- Disagree
- Disagree strongly
- Don't know

Which of the following areas do you think is high, medium or low priority for medical technologies spending?

Q24: Preventative medicine – where devices can be used to diagnose the potential onset of diseases at an early stage

- High priority
- Medium priority
- Low priority

Q25: Implants which can monitor a patient's health and release therapeutic agents such as drugs inside them

- High priority
- Medium priority
- Low priority

Q26: Infection control, where there is a focus on the fast detection and control of things like hospital bugs such as MRSA

- High priority
- Medium priority
- Low priority

Q27: Regenerative medicine, where there is a focus on helping the body to repair tissues that has been damaged though injury or diseases

- High priority
- Medium priority
- Low priority

Q28: New methods of drug discovery, to increase speed, effectiveness and cut down on the use of animal testing

- High priority
- Medium priority
- Low priority

Q28: Personalised medicines, where you test people's likely reaction to taking new medication and to tailor a treatment for them based on the test results

- High priority
- Medium priority
- Low priority

Q29: Better means of drug delivery, to reduce the side-effects, cut down on costs, and to target areas of the body which it is hard to get drugs to effectively, such as the brain.

- High priority
- Medium priority
- Low priority

Q30: And if you had to prioritise them, which would be your top 3 issues for us to explore in more depth in the next workshop (press three numbers only)

Q31: And if you had to prioritise them, which would be your top 3 (press three numbers only)

1. Preventative medicine and early stage diagnostics
2. Implants to monitor diseases and realise drugs
3. Controlling bugs such as MRSA
4. Regenerative medicine – helping the body to repair tissues
5. Quicker ways for drug discovery
6. Personalised medicines – helping to tailor medicines and treatments for individuals
7. Drug delivery

8. None of these

Appendix 2: Topic guide for workshop 2: Nanotechnology applications

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08.05.2008

Nanotechnology Workshop 2:

Time	Session and aims	Topic areas	Tools/ Stimulus material
10.30-10.45 Whole group	*Session 1: Welcome and introduction* Introduce session Feedback Capture views on priorities prior to discussion	Overview of workshop EPSRC rep to highlight Grand Challenge call by EPSRC Feedback from findings of workshop 1 Voting on research priorities	Presentation on findings from workshop 1 IML voting (see annex 1)
10.50-12.15 Small groups	*Session 2: Discussion of case studies 1-3* *Explore views on medical benefits and concerns in relation to diagnostics, infection control and drug discovery.*	Welcome and introduction Brief discussion of any info people found out on nano in the interim **Case study 1: Diagnosing illness** General discussion and points of clarification • Is this an important area of research – why probe ○ Aspirations and concerns • Is early diagnostic information	Case studies (see annex 2) Scientist/ ethicist as resource for group

		empowering or disabling • Views on self diagnostics probe o chronic and acute conditions o worried well • Role primary care: trust/ competence of doctor to carry out test • Access to information from 3rd parties • Overall is this a high, medium or low priority - why **Case study 2: Detecting and killing bugs** General discussion and points of clarification • Is this an important area of research – why probe o Aspirations and concerns • Views on uses: hospitals; food; security • Views on environmental and health impacts • Potential to create super bugs • Views on less high tech solutions (e.g. washing hands) • Overall is this a high, medium or low priority - why **Case study 3: Drug development** General discussion and points of clarification • Is this an important area of research – why probe o Aspirations and concerns • Should public money fund this probe o Potential commercial benefits	

		○ UK's economic success • Views on cutting down on use of animals in drugs development • Views on personalised medicines probe ○ Uneconomical to treat people with individualised medicines? • Views on investment given other areas of research that may have more impact • Overall is this a high, medium or low priority – why Thinking across all three areas, which one should be the highest priority and which the least – and why.	
12.20-12.30 Whole group	Feedback	Reporting back findings from morning	
12,30-1.15	Lunch		
1.15 – 2.45 Small groups	*Session 3: Discussion of case studies 4-6* *Explore views on medical benefits and concerns in relation to regenerative medicine, drug delivery and theranostics.*	**Case study 4: Regenerative medicine** General discussion and points of clarification • Is this an important area of research – why probe ○ Aspirations and concerns • Views on having small nano-scaffolds in body • Views on clinical risks probe ○ Fate/ toxicity of implants ○ Should patients be able to consent to experimental treatments providing the risks are made clear Overall is this a high, medium or low priority - why	Case studies (see annex 3) Scientist/ ethicist as resource for group

		Case study 5: Drug delivery General discussion and points of clarification • Is this an important area of research – why probe o Aspirations and concerns • Views in relation to anti-cancer drugs; 'biologics' (probe costs); and hard to reach tissues • Views on clinical risks Probe o Any differences in views on risks relation to regenerative medicine? • Views on relationship with clinicians • Overall is this a high, medium or low priority – why **Case study 6: Theranostics** General discussion and points of clarification • Is this an important area of research – why probe o Aspirations and concerns • Views on targeting finance on single conditions such as diabetes – vs focus on wider research tools • Views on implants which monitor and treat body Probe: o devices being self controlled or controlled externally • Views on clinical risks Probe o Any differences in tolerating risks relation to the regenerative or drug delivery? • Views on uses for enhancement • Views on relationship with clinicians	

		• Overall is this a high, medium or low priority – why Thinking across all three areas, which one should be the highest priority and which the least – and why	
2.45-3.00pm	Break		
3.00-3.30pm Whole group	*Session 4:* Feedback and voting To prioritise research areas	Feedback - reporting back findings from afternoon session Interactive voting using IML technology to help prioritise which areas of research the public would most like to see taken forward. Thanks and next steps Hand out evaluation sheets	IML voting on key tracking questions (see annex 4)
3.30	Ends		

Annex 1: IML Voting Questions

Which of the following areas do you think is high, medium or low priority for medical technologies spending?

Q1: Early diagnostics – where devices can be used to diagnose the potential onset of diseases at an early stage

- High priority
- Medium priority
- Low priority

Q2: Detecting and killing bugs, where there is a focus on the fast detection and control of infections such as MRSA

- High priority
- Medium priority
- Low priority

Q3: New methods of drug discovery, to increase speed, effectiveness and cut down on the use of animal testing

- High priority
- Medium priority
- Low priority

Q4: Regenerative medicine, where there is a focus on helping the body to repair tissues that have been damaged though injury or diseases

- High priority
- Medium priority
- Low priority

Q5: Better means of drug delivery, to reduce the side-effects, cut down on costs, and to target areas of the body which it is hard to get drugs to effectively, such as the brain.

- High priority
- Medium priority
- Low priority

Q6: Implants which can monitor a patient's health and release therapeutic agents such as drugs inside them

- High priority
- Medium priority
- Low priority

Q7: And if you had to prioritise them, which would be your top 3 (press three numbers only)

9. Preventative medicine and early stage diagnostics
10. Implants to monitor diseases and realise drugs
11. Controlling bugs such as MRSA
12. Regenerative medicine – helping the body to repair tissues
13. Quicker ways for drug discovery
14. Drug delivery
15. None of these

Annex 2:

Case study 1: Diagnosing illness

A potential use of nanotechnology is for healthcare diagnostics. One area of interest is 'lab on a chip' technologies. For use outside of the body, these devices generally involve you placing a small amount of blood, saliva or urine on a microchip. The chip then analyses this sample for various molecular markers of wellness and gives you the results. A number of potential conditions could be analysed at the same time – essentially providing you with a 'health MOT'. The chips could be used in the comfort of your own home or in consultation with a doctor.

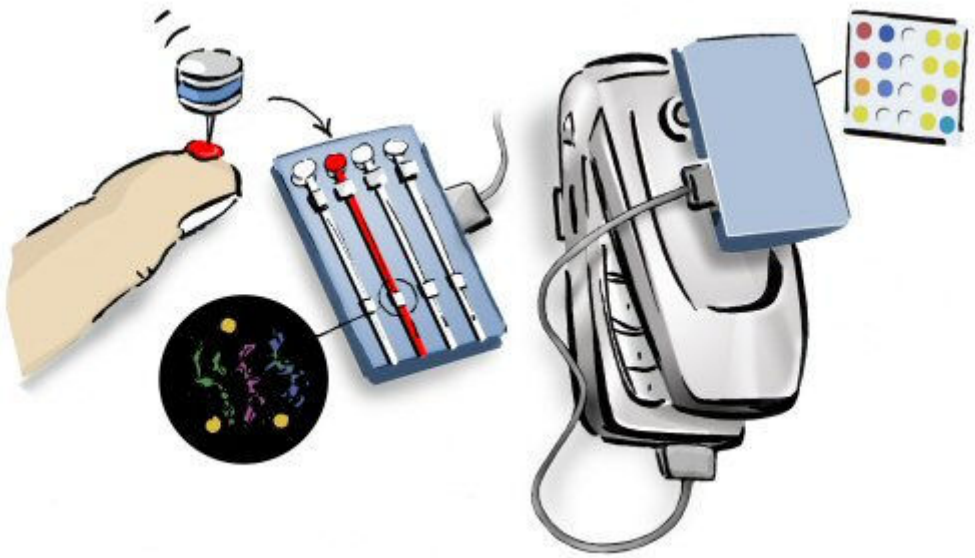


Illustration of 'lab on a chip' technology

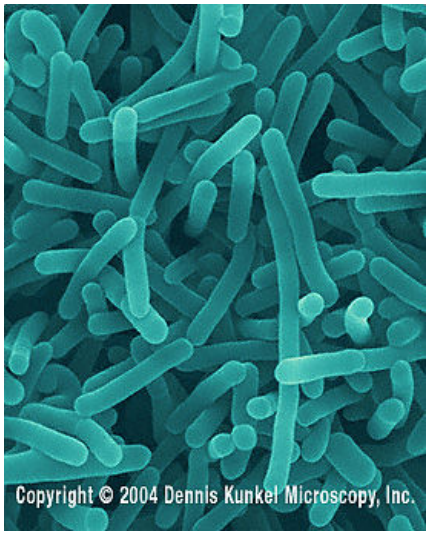
'Lab on a chip' technologies can be useful for preventative medicine – that is helping to diagnose illness such as cancers at an early stage before it has progressed too far. People with an increased risk for a certain disease could benefit from regular personalised check-ups to monitor changes in the pattern of their health.

While such monitoring could help decrease healthcare costs by enabling people to be treated at the onset of a disease, there are a number of concerns with these advances. It has been argued such devices could also exacerbate the anxieties of the 'worried well' - with people unnecessarily concerned about potential diseases. Such tools could also lead to the diagnosis of predisposition for a disease without an existing therapy. Early diagnostics are not 100% accurate or reliable. There may also be issues in interpreting and acting on the results if done by patients rather than doctors.

Finally there are significant privacy issues. Such devises will generate a significant amount of medical information. Access to this by insurance companies or employers is a concern for some people.

Case study 2: Detecting and killing off bugs

Infection control is a major public health issue in the UK. In our hospitals, MRSA caused some 1700 deaths in the UK in 2006 – up from 51 in 1993. In the past decade, there has been an 80 per cent increase in the number of British cases of listeriosis - often caused by contaminated mouldy cheeses, pâtés and raw meat. There are around 500 deaths per year from food borne bacteria – over a quarter of which are from listeria. Air borne pathogens - such as such as the avian flu virus – led to the culling of approximately 28600 birds in the UK in 2007. There are also concerns about the threat of bioterrorism – the deliberate attempt to infect people with viruses or bacteria.



Listeria bacteria

Nanotechnology offers the potential to develop a way to detect and eliminate pathogens on surfaces. A number of nanoparticles are known to have significant anti-bacterial and anti-viral activity. Devises will need to be active against a variety of pathogens, and there may need to be mechanisms for triggered release. Other important avenues to be explored are the development of self-cleaning surfaces. It is believed that 5 years is sufficient to make significant research progress in this area.

However, there are a number of issues around the use of nanotechnologies for infection control. We do not know impacts from the release of nano-particles on the people using them or on the wider environment. There is the possibility of the development of pathogen resistance to anti-microbial and anti-viral activity – creating a new generation of superbugs. Indeed, rather than a hi-tech solution, it has been argued that many cases of infection could be prevented with better hygiene.

Case study 3: Drug discovery

Discovering drugs is an expensive and time-consuming business. A typical single new drug can cost over £500 million to make and takes more than 10 years to develop. Pharmaceutical companies are increasingly seeking new drug discovery technologies that can improve R&D success rates and time to market.

A new drug typically takes over 10 years to get from the preclinical development phase to commercialisation

Nanotechnology can enhance the drug discovery process, through the miniaturization, automation, speed and reliability of assays – which establish the potency of a drug. It can also help the process of screening new targets, by focusing on how drugs work at the molecular level. There is the potential that such approaches could cut down on the use of animals for drug testing.

In addition, such advances open up the possibility of personalised medicines, where you test people's likely reaction to taking new medication and to tailor a treatment for them based on the test results.

In terms of funding, drug development already has significant investment from the private sector. It also should be noted that nanotechnology approaches, while important, are less significant that other developments in this area, such as the growth of human tissues from stem cells.

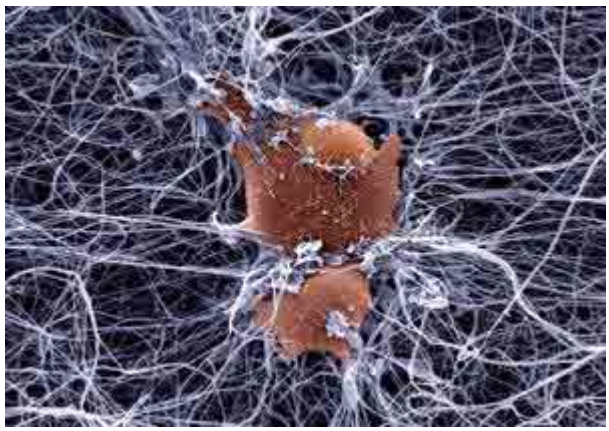
Annex 3:

Case study 4: Regenerative medicine

Regenerative medicine is a new way of treating injuries and diseases that uses specially-grown tissues and cells. From a nanotechnology perspective, the aim is to produce materials that can help control how tissues develop and how cells interact.

For example, one use of nanomaterials for regenerative medicine is to help form scaffolds to support cells that can be implanted into the patient to replace diseased or damaged tissues. With time, the scaffolds are reabsorbed and replaced by body's tissues.

This has a number of potential uses. At the moment tissue engineered skin is available for clinical use for severe burns and hard to heal wounds. The growth of new cartilage and bone for implantation is also reasonably close to clinical treatments. Growing replacement tissues for organs like kidneys, livers and hearts or regenerating nerves after spinal injuries are quite a lot further away.



Neural cells from a rat in a scaffold made from collagen and hyaluronic acid. The research involves the development of an injectable gel that can be used as a scaffold for regeneration of lost brain tissue.

One of the key research goals is get a better understanding of how nanostructures may influence how cells differentiate and grow. Not getting this right could mean that implanted tissue could grow abnormally and potentially cause cancer. Another issue is the fate and toxicity of nanoparticles after the scaffold or implant breaks down in the body. Much research is therefore needed before the full promise of regenerative medicines can be met.

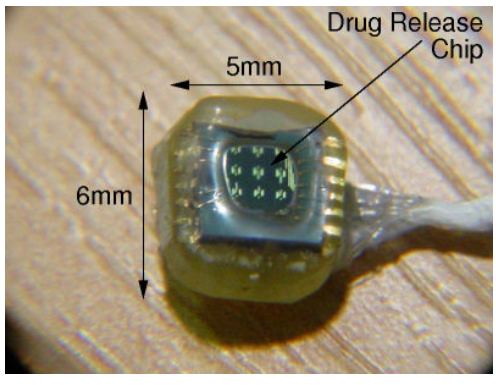
Case study 5: Drug delivery

There are a number of potential areas that nanotechnology can help address with regard to drug delivery. First is delivering highly toxic drugs - particularly anti-cancer chemotherapy drugs - in a way which gets a higher proportion of the drug to the target and less to the rest of the body, minimising serious side-effects. There are already some crude drug delivery systems already in use for this purpose.

Second is delivering a new class of 'biological medications' which are destroyed in the stomach and thus can't be taken as tablets. Some of these 'biologics' are currently delivered by injection, so advances would reduce or eliminate the need for frequent injection. Biologics are much more expensive than conventional drugs, and a drug delivery system would allow you to get the same effect from smaller doses. There are a large number of new and candidate drugs are in this category – for instance the breast cancer drug herceptin.

Third is delivering drugs to organs and tissues that are otherwise hard to reach - such as the brain. For instance roughly 90% of drugs showing therapeutic benefits to diseases like Alzheimer, MS and brain tumours cannot reach sufficient concentration in the brain in order to be effective. Nanomaterials hold the potential of penetrating the brain-blood barrier so that a successful intervention can take place.

To address these issues, one potentially interesting area is smart drugs, able to combine both a drug and a targeting agent to get it to a specific site. For instance, an example could be the development of cancer therapies – which could target malignant cells without the side effects of hair loss or nausea of current treatments.



Researchers at the University of Edinburgh are developing a drug release chip that could be permanently implanted into the body and would be capable of delivering daily doses of a drug for up to one year.

There will be a number of challenges involved in developing these drugs therapeutically. Health a safety concerns are paramount and the materials must be able to function correctly in the body and not have significant side effects. Also important will be to know the fate of nanostructures after the therapy has been delivered. To be successful, a grand challenge approach needs to engage with clinicians - an area of existing UK strength in academia. The strength of industry is also good in this field.

Case study 6: Combined diagnostics and therapies: theranostics

The idea behind 'theranostics' is to develop devices that combine both the diagnosis of a disease and the delivery of a therapeutic agent in a single system. Such devices would most likely target a single disease condition.

At its most simple level, one potential would be to develop a devise that would include a miniaturised diagnostic system that could be implantable in the body. This could be combined with a system to release a therapeutic agent.

The Daily T

Sunday, August 30, 2015

Big things from small scienc

UK scientists today hailed a breakthrough in the treatment of diabetes. New devices, called theranostics, are extremely small implants which can release a drug when it detects a rise in blood sugar. However, campaign groups are concerned that it is not still fully understood how the technology works in the human body.

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A possible future newspaper headline on theranostics

A more ambitious system would be to attempt to do develop a drug delivery system that is responsive to its environment – for instance which would release a drug if it detected the onset of a disease. A good example of this is diabetes, where you could make clear the link between detecting glucose levels in the blood and the need to release insulin in the correct quantity in response.

There are clearly many issues that need to be addressed. In addition to the potential toxicity and fate of such devices, there are also problems surrounding the kind of signals such a system could respond to (for instance internal or external), and how the devices would communicate. An additional issue would be the potential to use such devices not just to remedy diseases, but also for human enhancement.

For funding purposes, there is an issue about whether fund research examining broad general principles for theranostics or to target it at a specific disease or condition, such as cancer or diabetes.

There is obviously a need to have close contact with clinicians to determine how practitioners would want to use such systems or devices.

Annex 4: Repeat IML Qs and feedback

Which of the following areas do you think is high, medium or low priority for medical technologies spending?

Q8: Early diagnostics – where devices can be used to diagnose the potential onset of diseases at an early stage

- High priority
- Medium priority
- Low priority

Q9: Detecting and killing bugs, where there is a focus on the fast detection and control of infections such as MRSA

- High priority
- Medium priority
- Low priority

Q10: New methods of drug discovery, to increase speed, effectiveness and cut down on the use of animal testing

- High priority
- Medium priority
- Low priority

Q11: Regenerative medicine, where there is a focus on helping the body to repair tissues that have been damaged though injury or diseases

- High priority
- Medium priority
- Low priority

Q12: Better means of drug delivery, to reduce the side-effects, cut down on costs, and to target areas of the body which it is hard to get drugs to effectively, such as the brain.

- High priority
- Medium priority
- Low priority

Q13: Implants which can monitor a patient's health and release therapeutic agents such as drugs inside them

- High priority
- Medium priority
- Low priority

Q14: And if you had to prioritise them, which would be your top 3 (press three numbers only)

1. Preventative medicine and early stage diagnostics
2. Implants to monitor diseases and realise drugs
3. Controlling bugs such as MRSA
4. Regenerative medicine – helping the body to repair tissues
5. Quicker ways for drug discovery
6. Drug delivery
7. None of these