Pro or Con Nanotechnology? Support for Critical Thinking and Reflective Judgement at Science Museums.

Pro oder Kontra Nanotechnologie? Unterstützung von kritischem Denken und reflektiertem Urteilen im Museum.

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Preface

The present dissertation project was embedded in the context of a larger research project (Knowledge Media Research Center, Tuebingen; Deutsches Museum, Munich; Institute for Science Education, Kiel) on learning in the museum by means of new media, which is funded by the "Pact for research and innovation" of the German Federal Ministry of Education and Research (http://www.iwm-kmrc.de/museum). In this three-year interdisciplinary research project, the educational potential of advanced media applications within the context of science exhibitions was explored with regard to knowledge acquisition, the development of interests and the formation of opinions. The following dissertation project is only one of about 12 research projects that will further contribute to our understanding of informal learning from science exhibitions and the role advanced media applications can play in this context. I tremendously profited by the input of my research colleagues who contributed a lot to the development of my ideas. So have considerations presented in Part I of this dissertation been arisen from intense collaboration with Dr. Carmen Zahn and Mag. Eva Mayr.

During 2005 to 2008, I have been participating in the Virtual PhD-Program "Knowledge Acquisition and Knowledge Exchange with New Media" (VGK; http://www.vgk.de) sponsored by the German Research Association (DFG). The VGK enabled me to collaborate with researchers from three German universities (Tuebingen, Muenster, Freiburg) in order to share ideas and knowledge, and to gain insight into other research projects. This dissertation benefited hugely from discussions with my VGK-fellows and the involved faculty members (Prof. Hesse, Prof. Bromme, Prof. Spada, Prof. Diehl, Prof. Gerjets, Prof. Fischer, Prof. Renkl, Prof. Plötzner, Prof. Strube).

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Due to the rapid growth of new technologies, the lay public today is faced with very complex science topics like climate change, gene technology and cloning, nuclear power, and nanotechnology. These topics share the characteristic of being highly ambivalent, and they all have profound social, political, and economic implications. These topics are referred to as *socio-scientific issues* because of their social *and* scientific relevance (e.g., Kolstø, 2001; Sadler, 2004a). Socio-scientific issues often are a matter of intense discussion among various actors with competing perspectives and arguments (Oulton, Dillon, & Grace, 2004). The above cited news headlines about nanotechnological innovations are only a few examples of the ones released recently[1], but they depict the ambivalent information, the lay public today is confronted with. To be able to participate in the public debate about nanotechnology (or another 'hot' science issue), the lay public must have abilities to form their personal opinions. To reach a well-founded reflective judgement, it must be able to analyze and evaluate information, to deal sensibly with moral and ethical implications of current scientific topics, and to understand connections inherent among these issues (Oulton et al., 2004; Zeidler, 1984). Thus, making, defending and evaluating personal judgements

[1] All news headlines received October 27, 2008, from http://www.nanowerk.com/, a website which collocates nanotechnology research and general news from various resources (newspaper, research journals and press releases).

has become a central aim of (science) education today (King & Kitchener, 1994; Sadler, 2004b).

A major contributor for communicating contemporary science and thereby one of the places where public opinion is formed are *science museums* (cf. Institute for Learning Innovation, 2007; Rodari & Merzagora, 2007). Bradburne (1991, revised 2001) states that museums can be an ideal place for presenting and continuing contemporary debates, as they are experienced as a neutral place for discussion without political bias. Moreover, presentation of facts and figures within the context of science exhibitions can provide an excellent ground for public debates (Calcagnini, 2007). The understanding of a good museum thus has shifted from collecting and presenting loose objects to promoting *public understanding of science* and opinion formation (Durant, 1992). This manifests in a movement towards an emphasis of critical thinking skills at museums (e.g., special issue on critical thinking skills in the museum of the Journal of Museum Education edited by Shulman Herz, 2007). Science exhibitions today not only communicate scientific knowledge and uncover scientific discourses in our “knowledge-creating civilization” (Scardamalia & Bereiter, 2006, p. 97) but promote the acquisition of advanced expertise, such as scientific literacy, in visitors (e.g., Miles & Tout, 1992; Miller, 2001; Schauble et al., 2002; Thomas & Durant, 1987). And a very central part of scientific literacy includes the ability to make informed decisions and reflective judgements about contemporary science issues (cf. Zeidler, Sadler, Simmons, & Howes, 2005).

The present dissertation centres on the communication of contemporary science topics by means of science exhibitions, the need for critical thinking and reflective judgement, and the need for support of museum visitors in forming their personal opinions about these complex issues. This was motivated by the present lack of a clear conceptualization of scientific literacy, which includes deliberate opinion formation and informed decision making about current socio-scientific issues. The present dissertation addresses this gap of research by analysing how people form their opinions about a contemporary science topic like nanotechnology within the context of a science exhibition and which preconditions are essential to stimulate critical thinking in museum visitors. The notion of needs for scaffolding critical thinking and reflective judgement at science museums is a further central aspect to the present dissertation.

The two major conceptual research questions of this dissertation are therefore:

I. What constitutes critical thinking and reflective judgement about contemporary, controversial science issues within the context of science exhibitions?

II. How can museum visitors be supported in critical thinking and reflective judgement about contemporary, controversial science issues?

To answer these research questions, I will refer to several lines of research that have been concerned with reasoning and decision making, opinion formation, and critical thinking for the purpose of reflective judgement: Cognitive psychology, for example, provides us with valuable knowledge on individual reasoning and decision making. Research shows that heuristics and biases operate when people are confronted with controversial and ambivalent information, which then leads to suboptimal opinions and attitudes (e.g., Stanovich & West, 1997, Toplak & Stanovich, 2003). For example, people usually rely on prior attitudes or general attitudes when asked to evaluate a new concept (Nickerson, 1998). Felton and Kuhn (2007, p. 103) state in their contribution for the special issue on critical thinking in museums that "critical thinking requires considerable effort, and visitors will only engage in the cognitively complex work of critically evaluating their knowledge if they believe that it is worth the effort." They argue that museum visitors will not show critical thinking automatically and that for this reason, scaffolds for deliberate opinion formation are needed to overcome these biases and to facilitate formation of well-founded opinions.

To enhance critical thinking, *conversation* is a powerful tool (Felton & Kuhn, 2007; Halpern & Nummedal, 1995; Knipfer, Zahn, & Hesse, 2007, Zohar & Nemet, 2002). It has several potential cognitive benefits as collaborative learning theories assume: Collaborative learning theories consider learning and conceptual change to be the result of social interaction, and individual cognition is mediated through social processes (Piaget, 1985; Vygotsky, 1986). Science education as well points out that *classroom discourse* is an adequate account for teaching socio-scientific issues in terms of creating dissonance, thereby allowing for re-examining one's beliefs and thought-processes (cf. Zeidler et al., 2005). This dissertation focuses on the cognitive processes underlying discursive activity to highlight what constitutes potential for learning about contemporary science topics. For this purpose, I will also build upon knowledge from social psychology, which has extensively researched the mechanisms of social influence on individual judgement.

Empirical museum research supposes that social interaction and conversational engagement are indeed a matter of special importance for science learning at museums (Ellenbogen, Luke, & Dierking, 2004; Falk & Dierking, 1992; Leinhardt & Crowley, 1998; Leinhardt, Tittle, & Knutson, 2002; vom Lehn, Heath, & Hindmarsh, 2002). Explicit dialogue and discussion among visitors were shown to foster reconsideration and hypothesizing about the exhibition topic (Overwien, 2000).

I conclude from these theoretical considerations from both the perspectives of cognitive, educational and social psychology, and the supporting empirical results from the area of science education and museum research that social interaction in form of opinion exchange and debate is crucial for critical thinking and reflective judgement about contemporary science issues in the context of science exhibitions at museums. I therefore propose that *discussion and debate among visitors* are major facilitators of critical thinking.

To support discussion and debate, advanced media applications can play an important role by means of providing ‘spaces for dialogue’. Figure 1 shows exemplary design proposals that follow the current trend to personalize exhibition content, to evoke emotions, to involve museum visitors in active discussion.

Figure 1. Design proposals for innovative discussion-based media applications (Kaiser-Matthies, Berlin, for Deutsches Museum, Munich)

I will refer to this kind of media application by the term *discussion terminals*, as opinion expression and opinion exchange among visitors is central here. Discussion terminals are considered as a conceptually innovative type of interactive media application where contrary opinions of experts, concerned people, or laypeople are presented on controversial science topics, and visitors are allowed to contribute their personal conclusion. Implementation of such discussion terminals aims at raising awareness of controversy, supporting critical thinking, and enhancing reflective judgement. These media applications provide opportunities for opinion exchange and debate among visitors that go *beyond* the actual exhibition setting. Discussion terminals have the potential to promote critical thinking and reflective judgement by engaging visitors in argumentative debate about ‘hot’ science issues.

Despite the potential of discussion terminals for critical thinking and reflective judgement about socio-scientific issues, there is a gap in research with regard to the concrete learning mechanisms addressed by these media installations and their effects on critical thinking and opinion formation. The third, empirical research question to be addressed by the present dissertation is therefore:

III. How can discussion-based media installations stimulate critical thinking and reflective judgement about contemporary science topics within the context of exhibitions?

To investigate the potential of discussion terminals for critical thinking and reflective judgement, in *Chapter 1*, the learning potential of advanced media applications for knowledge communication at science museums in general will be discussed. This analytical discussion is based on both a review of existing media applications in science museums and knowledge from educational psychology on central mechanisms of collaborative learning.

In *Chapter 2*, these general analytical considerations on the potential of advanced media installations for knowledge communication at science museums will then be applied to examine the specific potential of discussion terminals for the communication of emergent technologies and contemporary science topics. Research on informal reasoning and critical thinking is reviewed to identify factors that are crucial for deliberate opinion formation and reflective judgement in the light of ambivalent and conflicting information. Based on these theoretical considerations, design requirements for a discussion-based media application for communicating contemporary science topics will be derived.

To yield deeper insights with regard to the educational potential of discussion terminals, two experimental studies were conducted: Study I focused on individual judgemental processes and the impact of the active expression of a personal opinion at a discussion terminal. Study II more explicitly addressed opinion exchange and debate among visitors by means of the discussion terminal and examined the effect of information about others' judgement. In *Chapters 3 and 4*, the methods and results are presented and discussed in the light of former research.

In *Chapter 5,* I provide a general discussion of the theoretical and practical implications of this research. Considerations on the generalizability of the study results and an outline of issues for future research are presented.

To summarize, the purpose of this dissertation is to synthesize knowledge from lines of research concerned with critical thinking and reflective judgement (cognitive, educational, and social psychology, public opinion research and science communication, and science education). This allows for a well-founded conceptualization of critical thinking, reflective judgement, and opinion formation about contemporary science issues at science museums. Based on these conceptual considerations, requirements for the support of critical thinking and reflective judgement will be generated. This will in the first enable us to carefully design advanced media applications as scaffold for learning about contemporary science issues in the context of science exhibitions. Both the developed conceptual framework and the empirical examination of a prototypical discussion terminal aim at broadening our understanding of how lay people form their opinions about a contemporary science topic and how we can successfully support them in reflective judgement about socio-scientific issues, “which shape our current world and will determine our future world“ (Sadler, 2004a, p. 514).

1 Part I: Advanced Technologies for Knowledge Communication in Science Exhibitions

For the purpose of this dissertation, science exhibitions are conceptualized as *dynamic information spaces for knowledge building* that are constituted by three major pathways of knowledge communication[2]: museum-to-visitor, visitor-to-visitor, and visitor-to-museum knowledge communication. By knowledge communication, I refer to the dissemination, exchange, and co-construction of knowledge. It is contended that each of the proposed major knowledge communication pathways relies on specific mechanisms of learning and must therefore be supported by specific kinds of advanced technologies.

In the following, the potential of advanced technologies for knowledge communication *among* visitors is emphasized. The focus will therefore lie on the second pathway of knowledge communication, namely visitor-to-visitor knowledge communication. A major reason for this is that previous museum-related research points out that social interaction and conversational engagement are highly relevant for knowledge acquisition in science exhibitions (Ellenbogen et al., 2004; Falk & Dierking, 1992; Leinhardt & Crowley, 1998; Leinhardt et al., 2002; vom Lehn et al., 2002). If we consider communication of contemporary science topics with the purpose of enhancing public understanding of science and technology as a major goal of modern science museums, discussion and debate among visitors as a specific form of visitor-to-visitor knowledge communication are a very promising way to foster critical thinking and reflective judgement at science museums. Media applications can not only support visitor-to-visitor communication, as will be argued in this chapter, but they also enable

[2] Museums have already been referred to as communication systems in former research (cf. Hooper-Greenhill, 1991; Whittle, 1997).

new forms of knowledge communication among visitors. The discussion terminals presented above, for example, enable new forms of communication among visitors beyond temporal boundaries (see figure 1 in the introduction section).

However, I will review advanced technologies applied in science exhibitions that have *not* been explicitly designed to support knowledge communication among visitors. In fact, interactive media are often constrained by very small displays not suited for more than one person or by the lack of opportunities for direct manipulation by more than one visitor at a time (Heath, vom Lehn, & Osborne, 2005). Another challenge is the trade-off between interactive media use and social interaction: Walter (1996) found that with increased visitor-media interaction, a decline in visitor-visitor interaction could be observed. In their video-based field study, Heath et al. (2005) also observed “that these new tools and technologies, whilst enhancing ‘interactivity’, can do so at the cost of social interaction and collaboration” (p. 91). Thus, I argue that it is not sufficient to introduce advanced technologies in science exhibitions for their own sake. In order to successfully face the challenges described above, it is crucial to develop a full understanding of science exhibitions as dynamic spaces for knowledge building by integrating perspectives from both museum research and educational psychology.

This conceptualization will enable us to systematically analyze the learning mechanisms that might (or might not) be addressed in science exhibitions, so that we can then research them in systematic ways and design advanced technologies that explicitly facilitate knowledge communication. For this purpose, both an overview on media applications in science exhibitions is provided and their potential for knowledge communication and learning is discussed thereby drawing on knowledge from educational and cognitive psychology. Specific mechanisms of collaborative learning are identified which should inspire the design of innovative media applications that explicitly support knowledge exchange and learning in science exhibitions.

1.1 Science Exhibitions as Dynamic Information Spaces for Knowledge Building

What are the distinct features of science exhibitions with respect to knowledge communication processes? One major characteristic is the presentation and explanation of scientific knowledge through *presentation of authentic objects* (Gramelsberger, 2006). Such authentic exhibits with their inherent aura (cf., Benjamin, 1936) are designed to elicit both individual learning and social interaction, such as communication between scientists and laypersons, within visitor groups like families or friends, and even among unacquainted visitors. Since authentic objects are seldom self-explanatory, learning is often supported by advanced-technology “labels” which provide further explanations and - above all - reasons to explore an object more extensively. Thus, science exhibits typically comprise the authentic object(s) plus text labels and/or advanced media applications like film, information terminals, or interactive tools for contextualization, explanation, facilitation of understanding, and arousal of interest. Therefore, exhibitions have often been referred to as rhetorically complex arguments (Scholze, 2004) or rhetorical events (Knutson, 2002). This notion also takes into account the fact that exhibitions are carefully designed *information spaces*.

Another major characteristic of modern science exhibitions is that they not only present scientific objects, facts, and figures, but are particularly designed to provide possibilities for the visitor to actively participate in a collective knowledge building process. In this way, a constructivist approach to science learning is realized (Black, 2005; Leinhardt & Gregg, 2002; Schauble et al., 2002). In modern science exhibitions, advanced technologies enable self-guided exploration and social interaction to stimulate knowledge communication about scientific content among visitors (e.g., Ash, 2002). The constructivist approach focuses explicitly on visitor engagement and learning - defined by Perry (1993) as physical engagement with exhibits (“hands-on”), intellectual engagement ("minds-on"), emotional engagement (affective reactions), and social engagement (e.g., discussion among visitors). Thus, learning in science exhibitions is active and social in the sense that visitors themselves engage in knowledge building instead of being passive recipients within a complex information space.

Furthermore, this active visitor engagement is not restricted to the real museum space. Hsi and Fait (2005) emphasize the potential of advanced technologies to support communication and learning *beyond* the real museum site. Examples include learning collaboratories of science exhibitions (Kahn, 2007) or web-based "do-it-yourself" experiments that allow school classes to integrate museum field trips with their classroom activities before and after the visit[3]. Thus, learning in science exhibitions includes knowledge communication within and beyond the museum space.

These considerations led us to the general theoretical conception of a science exhibition as a *dynamic* information space for knowledge building, with its major constituents, actors and the setting itself varying continuously and reaching beyond the actual exhibition site and its present visitors.

1.2 Three Pathways of Knowledge Communication

Three *pathways of knowledge communication* are differentiated as the major constituents of the dynamic information space "science exhibition" (cf. figure 2):

A. The first pathway of knowledge communication comprises the communication of scientific expert knowledge to the visitor. This pathway is labelled the *museum-to-visitor pathway of knowledge communication*. Within this pathway, science exhibitions provide knowledge in a unidirectional, mass-media-like fashion (Treinen, 1990). This pathway of knowledge communication includes whole

[3] Retrieved April 21, 2008, from http://www.exploratorium.edu/visit/sci-studio.html

exhibitions, objects, and labels within exhibitions, but also more personalized knowledge communication like guided tours or guidebooks for visitors.

B. The second pathway runs among visitors. This pathway will be called the *visitor-to-visitor pathway of knowledge communication*. This pathway comprises both real-time, face-to-face, (media-supported) reciprocal communication (*knowledge dialogue*) and delayed, media-based or “virtual” knowledge sharing (*knowledge pooling*).

C. The third pathway is a “feedback loop” from the visitor back to the museum. This pathway is labelled the *visitor-to-museum pathway of knowledge communication* here. In this pathway, visitors may give feedback on exhibitions, provide additional information, correct mistakes, and, through all these activities, contribute to the museum’s knowledge base (communicated again to other visitors later on, thus re-entering in the first pathway of knowledge communication).

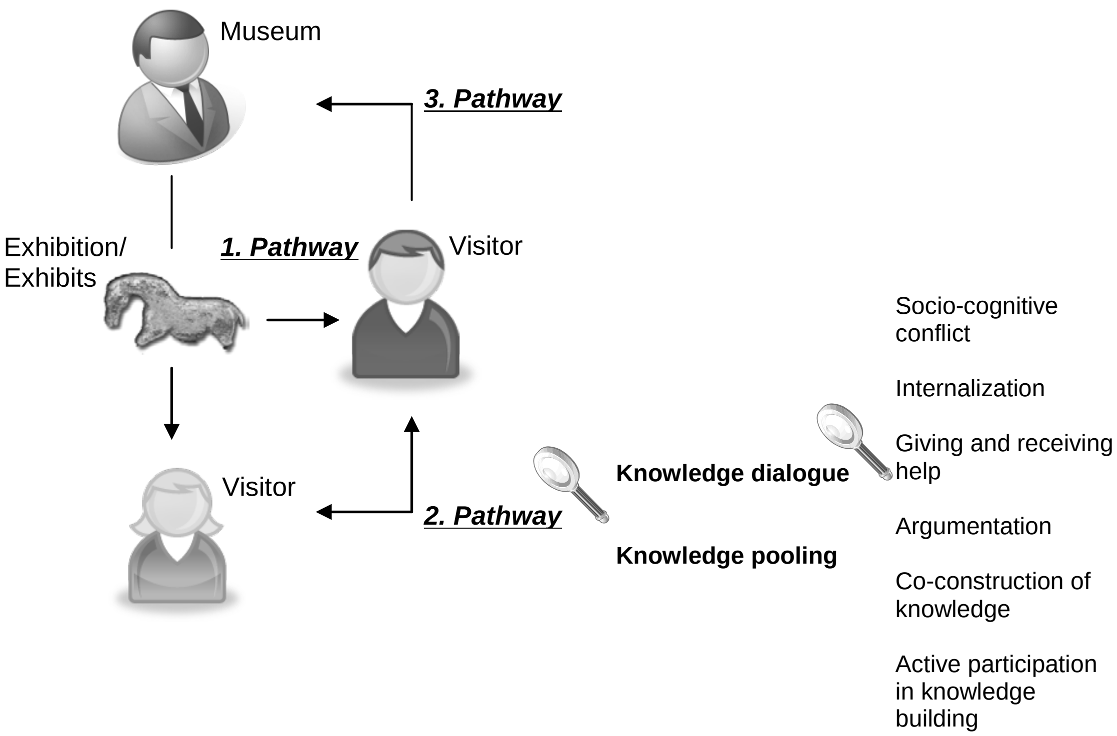

Figure 2. Science exhibitions as dynamic information spaces for knowledge building: Three pathways of knowledge communication and major forms of visitor-to-visitor knowledge communication with central learning mechanisms

Concerning the first pathway, a good deal of research has been conducted on the role of advanced technologies in supporting the presentation and explanation of exhibits (e.g., Ayres & Melear, 1998; Bell, Bareiss, & Beckwith, 1993/1994; Falk, Scott, Dierking, Rennie, & Cohen-Jones, 2004; Frost, 2002; Hapgood & Palinscar, 2002; Hsi, 2003; Reussner, Schwan, & Zahn, 2007). In contrast, the use of advanced technologies for visitor feedback in science exhibitions (third pathway) is still in its earliest stages and can only be discussed in terms of its future potential. The second pathway, however, is an emerging and challenging field of research. Knowledge communication *among* visitors is emphasized more and more strongly in practice, but is still somewhat underspecified in theoretical approaches. Hence, I will focus on the second pathway during the remainder of this chapter. The implications of this analysis for the design of advanced technologies supporting knowledge communication in science exhibitions will be considered.

In the following section, existing advanced media applications in science exhibitions will be discussed that support the second pathway of knowledge communication - knowledge communication *among* visitors.

1.3 Advanced Technologies for Visitor-to-Visitor Knowledge Communication

In this section, prototypical advanced media applications that can support knowledge communication between visitors will be presented. The presented media applications are assigned to two major types of visitor-to-visitor knowledge communication, namely *knowledge dialogue* and *knowledge pooling.* The notion of “dialogue” emphasizes the interactive and reciprocal nature of this knowledge communication process. Here, knowledge is mainly communicated real-time, co-located, and face-to-face. Knowledge pooling, however, comprises knowledge communication processes that are mainly asynchronous and media-based. This kind of knowledge communication also emphasizes the idea that visitors' knowledge and experiences are "pooled" by means of advanced media applications. This knowledge communication process is a form of one-to-many communication where visitors share their knowledge for later retrieval by other visitors. In the following, advanced media applications for these two forms of knowledge communication will be discussed.

1.3.1 Advanced Technologies for Knowledge Dialogue

Knowledge dialogue has been intensively studied by various researchers in the field (e.g., Ellenbogen et al., 2004; Falk & Dierking, 1992; Leinhardt et al., 2002; vom Lehn et al., 2002). Leinhardt and Crowley (1998) even place *conversational elaboration* in the centre of their model of museum learning as a form of knowledge dialogue. Conversation has been studied both as process and outcome of learning at museums. It has been found that conversation is a major learning activity in museums (e.g., Crowley & Jacobs, 2002; Morrissey, 2002).

Advanced technologies that support knowledge dialogue might enhance learning in science exhibitions: *Within a visitor group*, conversational elaboration of content can be supported, for example, by adapting information (e.g., on a mobile guide) to visitors' shared interests, prior experiences, and prior knowledge. This adapted information establishes a relation between exhibits and the group's common ground (i.e., shared knowledge that constitutes the basis for communication) and thereby also encourages communication within this group (Mayr, Zahn, & Hesse, 2007). Adaptation of information based on prior movements (cf. Oppermann & Specht, 2000) within a group allows for the establishment of connections between different exhibits, and this in turn enhances conversational elaboration of content. Another possibility for supporting communication within a group is to provide each visitor with different information about an exhibit and encourage exchange of this knowledge (Kruppa, Lum, Niu, & Weinel, 2005). Woodruff et al. (2002) found that individuals exploring an exhibition in dyads, each with an individual audio guide, used the information from both guides to build and elaborate on this shared information by means of eavesdropping on the other's audio stream.

Some media installations even involve *unacquainted visitors* in knowledge dialogue. I consider this a major potential of advanced technologies in science exhibitions. For example, the London Science Museum displays controversial questions on a large table, and visitors can vote on these issues by pressing the buttons "*yes*" or "*no*" (vom Lehn et al., 2002). The displayed results then serve as a starting point for face-to-face discussion. Such installations follow the current trend of implementing discussion spaces, which I have already introduced in the first chapter and which is noticeable in the context of exhibitions about contemporary scientific topics that involve a certain degree of ambivalence and controversy especially (e.g., gene technology).

Discussion with other family members *after the visit* was found to be a primary factor for the formation and retention of museum-visit memories (Hooper-Greenhill & Moussouri, 2002). To elicit and support post-visit engagement with exhibits at the Exploratorium (San Francisco), visitors can photograph themselves engaging with specific exhibits and take these photos home with them to elicit and facilitate discussion of their experiences (Fleck et al., 2002). Wessel (2007) presents an advanced media application that allows visitors to take home exhibit information by bookmarking it on a PDA. These personalized "trails" of a museum visit can be accessed on the museum's website later on and both aid individual post-visit engagement and serve as a starting point for communication about the visit with family or friends.

1.3.2 Advanced Technologies for Knowledge Pooling

Communication about exhibits among unacquainted visitors and beyond temporal boundaries is made possible by means of advanced technologies: Visitors share information, ideas, and opinions on exhibits that can be retrieved later on by other visitors. There is growing interest in stimulating conversation through exhibits that bring up controversial questions (Rodari, 2005). Here, I see great potential in advanced media applications: Museums might not only provide information about competing viewpoints and sources, but also place visitors into the centre of the debate by giving them their own voice at so-called discussion terminals (Knipfer et al., 2007). Visitors can actively engage in public debate and leave their own opinions at these terminals to be retrieved by other visitors later on. Discussion terminals offer new possibilities for supporting communication and debate between visitors independently of their time of visit.

Similarly, social annotation technologies enrich the visiting experience by providing opportunities for knowledge pooling. Kateli and Nevile (2005) present an annotation technology for museum websites where visitors can add personal thoughts to an exhibition object. This annotation fosters visitors' knowledge pooling. On the website "Keskustelukartta", visitors can additionally link resources to specific objects (Salgado & Diaz-Kommonen, 2006). These examples of social annotation technologies have been developed for museum websites, but there are also successful installations within exhibitions themselves that allow for commenting (see also Stevens & Toro-Martell, 2003): Fushimi, Kikuchi, and Motoyama (2006) present a mobile-phone application to gather visitors' thoughts while they are exploring an exhibit. Visitors' comments are recorded and archived for retrieval by other visitors. Prior visitors' personal experiences and opinions can be accessed at the server and new ideas can be recorded later on.

Advanced technologies can also be used to support knowledge pooling within the context of more complex activities, like design activities: Visitors can create their own web galleries and share these with other visitors or the general public (e.g., “Ingenious” by the National Museum of Science and Industry, London[4]).

The presented advanced media applications are successfully implemented in science exhibitions. But do they actually support knowledge communication between visitors? Which forms of knowledge communication supported by advanced technologies are especially promising? Theories of collaborative learning are helpful for the design of advanced technologies as they unlock important learning mechanisms within visitor-to-visitor knowledge communication. Thus, in the next chapter, different collaborative learning approaches will be reviewed. The focus will lie on learning mechanisms that rely on knowledge communication. The identified mechanisms will be transferred to the context of science exhibitions, and I will discuss how this knowledge can inform the design of advanced technologies for visitor-to-visitor knowledge communication.

1.4 Learning Mechanisms in Visitor-to-Visitor Knowledge Communication

Collaborative learning is a concept that has been researched mainly in the realm of formal learning settings. Here, many empirical studies have shown the efficacy of collaborative learning in contrast to individual learning with regard to deeper elaboration, higher performance in formal assessment, better reasoning and problem solving strategies, lower stress level, higher levels of intrinsic motivation, and more positive attitudes towards learning and learning content (e.g., Johnson, Johnson, & Holubek, 1993). In general, collaborative learning elicits active, constructivist, and explorative learning situations that are crucial for higher learning outcomes (Slavin, 1990). Collaboration fosters motivation and interest - which are both crucial factors in

[4] Retrieved April 13, 2008, from http://www.ingenious.org.uk/Create/

learning (Berlyne, 1963, 1967; Hidi, 1990; Wild, Hofer, & Pekrun, 2001). These results from decades of research on collaborative learning are very outcome-oriented. To be able to inform the design of innovative advanced technologies for science exhibitions, I looked more closely at the processes of collaborative learning. Major mechanisms have been identified that are relevant for learning in science exhibitions, namely cognitive conflict, internalization of social processes, giving and receiving help, and argumentation (for extensive reviews on collaborative learning, see Konrad & Traub, 1999 and Webb & Palinscar, 1996), as well as further mechanisms based on newer theoretical accounts, namely group cognition and knowledge building. The validity of these accounts for informal learning will be discussed focusing on their significance for advanced media applications within the science exhibition context.

1.4.1 Learning through Socio-Cognitive Conflict

Theoretical background. Processing objectives can vary within a group: Individuals treat information differently because different perspectives, group norms, and members' roles shape processing objectives. Thus, group members' encoding strategies differ and result in different individual mental representations of a problem or concept (Hinsz, Tindale, & Vollrath, 1997). The learning gain of collaboration, therefore, is the intense elaboration on the learning material achieved by struggling with different understandings of a concept. Intense examination of different conceptual understandings and multiple perspectives can elicit a cognitive conflict, a "perceived contradiction between the learner's existing understanding and what the learner experiences" (Webb & Palinscar, 1996, p. 844). Piaget (e.g., 1985) assumed that a cognitive conflict leads to mental disequilibrium, which then elicits the search for further information and alternative concepts to resolve this cognitive conflict. Ideally, this leads to a higher mental state and better conceptual understanding. Newer theoretical accounts stress the role of social interaction in eliciting cognitive conflict and resolving this conflict through discussion and negotiation. Natasi and Clements (1992) emphasize the role of discussion in resolving socio-cognitive conflicts. Resolving conflicts by means of discussion can create a more complete and adequate representation of a problem.

Transfer to science exhibitions. When asked about their social interactions in science exhibitions, 10 % of visitors stated that they disagreed with each other about the exhibits (Packer & Ballantyne, 2005). Thus, conflict about exhibit interpretation is likely to be a salient factor of learning in science exhibitions. Ferguson (1996) also assumes that socio-cognitive conflicts are a major learning mechanism in family visits to science exhibitions, as family members act on different cognitive levels: It was found that exhibits that encourage interaction and debate between adults and their children might elicit cognitive conflict, fostering a deeper understanding of the content. Therefore, socio-cognitive conflict is an important instructional approach in the design of exhibits addressing controversial science topics (Knipfer et al., 2007). The underlying cognitive processes will be explained further in Chapter 2 of the present dissertation.

Advanced media applications. Earlier in this chapter, an installation at the London Science Museum has been described that displays controversial questions arising from contemporary science topics on a large table (vom Lehn et al., 2002). This installation displays visitor voting results and might therefore elicit socio-cognitive conflicts if there is disagreement between visitors. The socio-cognitive conflict might trigger face-to-face debate with other visitors and a further search for information ("Why do they think that?"). These considerations will be further explained in Chapter 2 to specify the potential of socio-cognitive conflict and disagreement for individual judgement about controversial science issues.

1.4.2 Learning through Internalization of Social Processes

Theoretical background. What if there are no different perspectives and no "clash of concepts" in a group? Vygotsky (1978, 1986) stated that cognitive development occurs through internalization of social processes - this means, in turn, that cognitive development requires social interaction. Knowledge is considered to be disseminated across learners by means of tools like language or shared artifacts. Others' ideas and abilities trigger further development; a learner learns during interaction just by thinking together with a more competent partner. Vygotsky (1978, 1986) established a theory of group learning that focuses on the "zone of proximal development" (ZPD). The potential for cognitive development depends upon the ZPD, a level of development that learners can attain when they engage in social behaviour.

Transfer to science exhibitions. As learners come with different prerequisites for interaction with an exhibit, they should be given the opportunity to access the exhibit's information in multiple ways. Ash (2004) argues that exhibits should be designed to provide multiple entry points to the ZPD. Moreover, exhibits serve as "shared space" for the externalization of individual knowledge. Learning - in the sense of Vygotsky (1978, 1986) - happens by means of building on ideas provided by others during conversation about an exhibit. The concept of conversational elaboration (Leinhardt & Crowley, 1998) builds on Vygotsky's work. Meaning emerges in the interplay between individuals acting in social contexts and the mediators - tools, talk, activity structures, signs, and symbol systems - that exist within these contexts. In the socio-cultural approach, researchers highly value the social context and assign group conversation a predominant role in learning through science exhibitions.

Advanced media applications. Kruppa et al. (2005) suggest using interindividual differences to enhance learning in a group: A computer model of the whole group is built by using knowledge gaps between group members to estimate at which exhibits maximal knowledge can be gained. At these exhibits, the system encourages knowledge pooling and can therefore enhance the learning experience for all group members.

Advanced media applications might even serve as “learning partners,” for example when pedagogical agents trigger interpersonal knowledge communication between a museum visitor and a virtual learning partner. The system might assess a visitor’s ZPD and provide assistance for elaboration only at those points where assistance is required. In this way, the technology could provide a framework of learning activities, which could, to a limited extent, include conversational activities and communication. But not only individuals might be supported by pedagogical agents who structure the learning process; groups could also be supported in their collaborative inquiry activities during the exploration of exhibits, for example through questions or prompts.

1.4.3 Learning by Giving and Receiving Help

Theoretical background. Asking questions and giving explanations are considered crucial learning activities, as they elicit metacognitive processes and self-evaluation (e.g., Kaartinen & Kumpulainen, 2002). Of course, help seekers profit from their interaction: Explanations given by a peer are often more helpful than explanations given by an expert, as peers have similar prior knowledge and are therefore able to produce more relevant and adequate explanations. Those giving this help also profit, because explanations require explication, restructuring, and knowledge transformation of one’s own understanding, not to mention continuous consideration of the recipient during the verbalization of explanations (Bereiter & Scardamelia, 1987b; Dehler, Bodemer, Buder, & Hesse, 2008).

Transfer to science exhibitions. Raising questions about exhibits and giving explanations to each other are quite typical activities in groups visiting a science exhibition (e.g., Crowley & Jacobs, 2002). Questions are an indicator of curiosity and situational interest, and they can elicit learning if answered (Wessel, 2007). Therefore, many museums deploy knowledgeable attendants who answer visitors' questions (e.g., Woodruff et al., 2002). Additionally, both questions and explanations are important aspects of conversational elaboration, which is a salient factor of learning at science exhibitions (Leinhardt & Crowley, 1998).

Advanced media applications. Raising and answering questions are especially typical conversational activities in parent-child visitor groups (Crowley & Jacobs, 2002). Often parents reach the limits of their knowledge when confronted with their children's questions. Advanced media applications could support parents in answering their children's questions by providing a repository of answers to frequently asked questions (FAQs) for each exhibit. These FAQs can be collected and answered by visitors (e.g., in a wiki) or provided by museum curators. The main constraint of such an advanced media application is the necessity of collecting an extensive number of questions and others' proposed answers. Of course, adults may use such a media application not only to satisfy their children's curiosity, but also to answer their *own* questions.

1.4.4 Learning through Argumentation

Theoretical background. As science topics often involve multiple perspectives of various actors and their arguments for or against an alternative, knowledge communication requires argumentative skills both to evaluate given arguments and also to express and defend one's personal opinions in discussions with other visitors. The negotiation of divergences of opinions or understanding through argumentation fosters learning threefold: First, expression of a personal opinion requires elaboration of available information, analysis and restructuring of given information, and organization of this knowledge for the purpose of arriving at a defensible position (Leitão, 2000). Second, argumentation during group discussion involves not only determining what to say but how to say it. This elicits higher-order thinking (e.g., in order to produce audience-appropriate explanations), which in turn results not only in recall of presented information, but also in transformation of this information (Bereiter & Scardamalia, 1987b). Third, discussion and debate require the consideration of counterarguments and the construction of well-founded rebuttals to defend one's personal opinion. The cognitive processes involved in debate and argumentation may improve the quality of acquired knowledge (Fischer, 2002).

Transfer to the science exhibitions. Science exhibitions are faced with the challenge of both presenting the ambiguity and controversy of contemporary science topics in their exhibitions and explicitly supporting visitors in developing and expressing deliberate opinions (Cameron, 2003; McLean, 2006). Museums increasingly place visitors into the centre of the debate by giving them their own voice (Cameron, 2003; Gammon & Mazda, 2000). Both reflective judgement about a controversial science topic and expression of a well-founded opinion have become major learning goals of modern science exhibitions (Bell, 2008). Rodari (2005) states that visitors seek social engagement around such topics by means of intense discussion and debate with their companions. Elaboration on and discussion of reasons for opposing positions can enhance elaboration on relevant arguments for a given alternative and thereby foster both critical thinking skills and the acquisition of factual knowledge (Knipfer et al., 2007). This assumption was tested in my second study, which will be reported in Chapter 4. In Chapter 2, the underlying theoretical considerations on the potential of disagreement and debate among museum visitors for critical thinking and reflective judgement will be further explained.

Advanced media applications. Pedretti (2006, p. 30) states that “spaces for dialogue […] enhance the spirit of inquiry, allow for a free exchange of ideas, and encourage the formulation and articulation of carefully thought out, defensible opinions.” I have already discussed the interactive tables at the London Science Museum, where visitors are encouraged to vote for given alternatives and to engage in face-to-face discussion to resolve disagreement. However, not only face-to-face discussion but also discussion-based computer terminals might provide valuable opportunities for learning about controversial issues in science exhibitions as will be further specified in following chapters of this dissertation.

1.4.5 Learning through Co-construction of Knowledge and Group Cognition

Theoretical background. Relatively new theoretical approaches see the group itself as the learning unit (Stahl, 2006). Knowledge is collaboratively built through negotiation and discourse. In this conception of learning, the group is more than the sum of individual contributions. Group cognition is seen as an emergent phenomenon where (a) the small group is the primary unit that mediates between individual learning and community learning; (b) community participation takes place primarily within small group activities; (c) individual learning is acquired largely through participation in these small group activities; (d) individual identities are formed and acknowledged through small group activities; and (e) community practices are enacted and reproduced through small group activities (Stahl, Koschmann, & Suthers, 2006).

Transfer to science exhibitions. Especially in science exhibitions, collaborative meaning-making can initiate cognitive elaboration processes (Rowe, 2002). Rowe points out that meaning-making in science exhibitions is a joint social activity: He sees the processes of meaning-making as “active co-construction”: Achieving understanding and making meaning are things people do actively, and that work is reflected in their conversations both in the themes of the conversations (what they say) they have during meaning-making activity and in the structures of the conversations and activities (how they say what they say).

Rowe (2002, p. 22) also states that an exhibit is not always understood in the way the exhibition designer intended. Instead, visitors co-construct their own meaning by means of conversation; the way they accomplish this is shaped by affordances or constraints of the exhibit itself. “As a result, the group, in effect, ‘knows’ more than any of its individual parts.”

Advanced media applications. Sumi and Mase (2001) developed a system called AgentSalon, which facilitates face-to-face discussion among people with shared interests at science exhibitions. The mechanism behind this system is integrating personal agents through a face-to-face discussion of two to five users. “The essential jobs of AgentSalon are to detect and represent shared/different parts of the personal information (e.g., interests and touring records) of several users” (ibid, p. 394). For this purpose, visitors use their personal PalmGuide to “feed” AgentSalon with personal information like interests, experiences, or opinions, which then “move” to the public screen in the form of an animated agent. Agents then automatically start a conversation around their shared interests, about common as well as differing opinions, or about similar and dissimilar experiences. Visitors can actively engage in this discourse and meaning-making process by elaborating on their agent’s information, thereby collaboratively creating new knowledge.

1.4.6 Learning through Active Participation in Knowledge-Building Processes

Theoretical background. Scardamalia and Bereiter (1994) introduced participation in knowledge building as an alternative form of education in today’s knowledge society. “A knowledge-building environment enhances collaborative efforts to create and continually improve ideas" (Scardamalia, 2003, p. 270). Learning is understood as a by-product of active participation of *all* members of a community in the knowledge-building process and comprises advantages in literacy as well as the acquisition of knowledge and skills. This approach has a broader focus than more traditional collaborative learning theories: Knowledge, in this account, comprises not only cognitive, but also external representations as products of group work (in this sense, Wikipedia is also a representation of community knowledge, regardless of whether or not this knowledge is also internalized by single community members). Knowledge building also comprises the assumption that individuals not only enlarge their own understanding by participating in the collective knowledge-building process, but that they assume cognitive responsibility for the advancement of collective knowledge in the community (Scardamalia, 2002).

Transfer to science exhibitions. As stated in the introduction, the advancement of community knowledge is a goal inherent to museums as institutions. However, it is still not quite clear who should actively participate in the collective knowledge building process: Curators? Designers? Visitors? Many museums are still reluctant to implement a consistent practice of true visitor participation and rather see themselves mainly as providers of expert knowledge for a lay public (cf. Trant, 2006). Even though feedback from expert visitors is used to improve exhibitions, visitors are usually not systematically integrated into the process of collective knowledge building. If a museum were to change its identity from provider of expert knowledge to a knowledge-building community including visitor participation, it could allow visitors to construct and enhance the knowledge within exhibitions – in the sense of Scardamalia and Bereiter (1994). Visitors could learn from knowledge contributed by other visitors. They could build upon this knowledge and create new knowledge that again might be used by other visitors for further learning and knowledge building.

Advanced media applications. Hoffmann and Herczeg (2005) suggest implementing a wiki called "Wikiseum" on a museum website. This wiki application allows for knowledge building by visitors themselves. Visitors engage in active manipulation of exhibition content; they can share their expertise with other visitors and personalize the virtual exhibition. This might not only increase motivation and interest but also create a lasting community of interest that communicates and shares knowledge for a longer period of time. The information space of the science exhibition can thus be expanded and is no longer restricted by time or location.

Another media application in which new knowledge is built by active visitor participation is social tagging, where information - "tags" - are supplied and shared by visitors (Trant, 2006). This new information comes from the visitors themselves and contributes not only to the museum's knowledge base, but also to a community's or society's knowledge. Thus, through such media applications, exhibitions can support knowledge building. Hall and Bannon (2005) used this approach in the Hunt Museum (Ireland): Visitors could record their own interpretation of four mysterious objects. Afterwards, other visitors' interpretations could be retrieved from a radio installation.

1.4.7 Concluding Reflections on Learning Mechanisms in Visitor-to-Visitor Knowledge Communication

In this chapter, mechanisms of collaborative learning have been presented that are addressed in visitor-to-visitor knowledge communication in science exhibitions. These mechanisms differ with respect to the degree to which they focus on either the *individual* (under social influences) or the *group* as a central learning unit. The two mechanisms "socio-cognitive conflict" and "internalization of social processes" imply that individual learners bring different background knowledge and different mental representations into the social learning situation, which makes it necessary to establish a joint understanding through knowledge communication. Central activities to establish this joint understanding are “questioning and explaining” and “argumentation”. Peers give help and assistance to each other, provide additional resources and information, give feedback about behaviour and ideas, and often hold different perspectives on and mental representations of a problem. Visitor-to-visitor knowledge communication is relevant, as individual mental representations can be incomplete and may be enriched or corrected by social interaction. In argumentative knowledge communication, negotiation of divergent opinions or understandings results in higher-order learning. The social situation creates opportunities for expressing and defending one’s own opinion about given alternatives, thereby fostering individual understanding.

In contrast to these mechanisms, “active participation in knowledge building” and “group cognition” are mechanisms *on the group level* itself: Both approaches assume that an individual contributes to the knowledge of the group (group cognition) or community (knowledge building) during manipulation of external representations. Individuals profit from group processes but are not the main focus of attention in related research. Here, an open question is which knowledge is ultimately internalised by an individual learner involved in group-learning processes. If group knowledge only exists “outside” the individual (e.g., in form of an external representation like a group product), it can only be traced when reified in artifacts (e.g., discussion terminals or wikis).

The mechanisms presented here are not mutually exclusive, though some of them are closely intertwined: For example, during knowledge building with external representations like wikis, learners might also experience and resolve a socio-cognitive conflict. If their representation of the issue does not fit in with the content of the wiki, they might finally manipulate the external representation. In laboratory experiments or carefully designed qualitative studies, collaborative learning can only be traced back to one single mechanism. In contrast, advanced technologies in science exhibitions can support more than one mechanism of collaborative learning simultaneously. The advanced media applications presented in this chapter were reviewed with respect to the question of which collaborative-learning mechanisms they support (cf. table 1). The results confirm that most advanced media applications support more than one mechanism.

1.5 Discussion

In this chapter, a framework for understanding informal learning in science exhibitions has been presented, and the potential of advanced media applications for visitor-to-visitor knowledge communication has been analysed. For this purpose, science exhibitions have been considered as dynamic information spaces for knowledge building. *Three pathways of knowledge communication* were proposed as the major constituents of this dynamic information space. Various advanced media applications which can support social engagement within the second, *visitor-to-visitor pathway* of knowledge communication were discussed with regard to their rationale based on theories of collaborative learning.

First, we can conclude that visitor-to-visitor knowledge communication appears in various forms, namely (a) one-way and two-way, (b) synchronous and asynchronous, (c) within and beyond existing groups, and (d) during and after the actual visit. Second, advanced technologies have the potential to support all traditional forms of visitor-to-visitor knowledge communication. Additionally, they enable *new forms* of knowledge communication like knowledge pooling (e.g., by means of social annotation systems or discussion terminals). Whether or not advanced technologies in science exhibitions are specifically designed to support certain forms of interpersonal knowledge communication or specific mechanisms of collaborative learning remains an open question.

Table 1. Overview of Advanced Media Applications: Addressed Forms of Knowledge Communication and Collaborative Learning Mechanisms

Media application	Reference	Form of knowledge communication	Mechanisms of collaborative learning					
			SCC	ISP	GRH	A	GC	PKB
Mobile guide	Mayr et al. (2007)	KD		X			X	
Mobile guide (Hippie)	Oppermann & Specht (2000)	KD[a]					X[a]	
Mobile guide	Kruppa et al. (2005)	KD	X	X			X	
Audio guide	Woodruff et al. (2002)	KD		X			X	
Tabletop display (London Science Museum)	Heath et al. (2005), vom Lehn et al. (2002)	KD	X	X		X		
Mobile guide, public display (AgentSalon)	Sumi & Mase (2001)	KD		X			X	
RFID, mobile guide, website (Rememberer)	Fleck et al. (2002)	KD					X	
Mobile guide, website (InterestTrail)	Wessel (2007)	KD[a]					X[a]	
Discussion terminal	Knipfer et al. (2007)	KP	X	X		X		

Website, social annotation	Kateli & Nevile (2005)	KP	X	X				X
Website, social annotation (Keskustelukartta)	Salgado & Diaz-Kommonen (2006)	KP	X	X				X
Video recording & display (VideoTraces, ArtTraces)	Stevens & Toro-Martell (2003)	KP	X	X		X		X
Mobile phone	Fushimi et al. (2006)	KP		X		X		X
Website (Ingenious)	National Museum of Science & Industries, London	KP		X		X		X
Website (Wikiseum)	Hoffmann & Herzeg (2005)	KP		X				X
Radio recorder & receiver	Hall & Bannon (2005)	KP	X	X		X		X
Website, social annotation	Trant (2006)	KP	X	X				X

Note. Two raters independently assigned the reviewed advanced media applications to the categories to ensure objectivity of categorization. Differences in categorization were resolved through intense discussion. KD = knowledge dialogue; KP = knowledge pooling; SCC = socio-cognitive conflict; ISP = internalization of social processes; GRH = giving and receiving help; A = argumentation; GC = co-construction of knowledge and group cognition; PKB = active participation in knowledge building.

[a] This media application does not support visitor-to-visitor knowledge communication per se; categorization refers to potential interaction or extensions of this media application as described in this chapter.

In the introductory section of this chapter, the findings of Heath et al. (2005) and Walter (1996) about the interaction-interactivity trade-off and other identified problems with interactive media applications have been presented. These problems suggest that most advanced technologies in science exhibitions could be improved by explicitly fostering collaborative learning mechanisms and visitor-to-visitor knowledge communication. Also, many of the reviewed advanced media applications did not focus on underlying mechanisms of learning but on (technical) design. A notable exception is the SHAPE-project (Hindmarsh et al., 2001). Here, mechanisms of learning in museums were first identified by extensive video field observations; this knowledge then informed the design of media installations in science exhibitions.

It was discussed how advanced technologies can address specific learning mechanisms based on collaborative-learning theories, socio-cognitive conflict, internalization of social processes, giving and receiving help, argumentation, group cognition, and active participation in knowledge building. As summarized in table 1, some mechanisms are more often addressed in advanced media applications than others. Why might this be the case? First, a possible explanation might be that some mechanisms can be supported by media technologies more easily than others. Second, the consideration of different forms of knowledge communication might be confounded with underlying assumptions about learning from science exhibitions. In the following, both points will be examined in detail.

Are some mechanisms for collaborative learning easier to support than others? It seems that particularly those mechanisms that build upon individual learner characteristics and that therefore result in very variable social interactions have been less frequently supported by advanced technologies so far. This applies especially to the mechanism “giving and receiving help” as a visitor’s search for help is difficult to predict. Even though frequently asked questions (FAQs) might help to answer prototypical requests for help, they can never cover all possible problems that might occur. Advanced media applications that can adapt to highly individual characteristics can be very effective in supporting knowledge communication. Therefore, a challenge for media designers in the next years will be the development of highly flexible technologies that take individual learner differences into account.

Other mechanisms that seem to be addressed less frequently in advanced media applications in science exhibitions are those that assign visitors an expert role: “giving and receiving help”, “group cognition”, and “active participation in knowledge building” build upon the assumption that visitors can successfully provide other visitors with knowledge and that they can add something valuable to the presented knowledge base of the exhibition. This is especially important for advanced technologies that facilitate the third, visitor-to-museum pathway of knowledge communication. In the review of advanced media applications, I focused on the second, visitor-to-visitor pathway of knowledge communication. However, advanced media applications like annotations systems or wikis have been presented that allow for active visitor participation in knowledge construction and knowledge presentation. To enable the implementation of advanced technologies that encourage active visitor participation, the self-image of museums has to further change from “knowledge displayer” to “provider of a knowledge platform”. Visitors must also change the expectations they have built based on their previous experiences at museums: They must adopt a more active role and participate in knowledge building. They are required to be willing to share their own knowledge and opinions with the museum and other visitors. This raises other questions of motivation for participation addressed in social psychology and media psychology (e.g., Ardichvili, Page, & Wentling, 2003; Cress & Kimmerle, 2007; Jarvenpaa & Staples, 2000; Kimmerle, Cress, & Hesse, 2007; Wirth & Braendle, 2006).

Are the supported mechanisms of collaborative learning confounded with implicit learning theories for learning in science exhibitions? Schauble, Leinhardt, and Martin (1997, p. 4) argue for a sociocultural approach to museum learning research: This allows for meaning-making within a social context rather than learning through facts and figures and emphasizes “the interplay between individuals acting in social contexts and the mediators - including tools, talk, activity structures, signs, and symbol systems - that are employed in those contexts.” At the moment, many museum researchers build on sociocultural theory to explain learning (cf. Falk & Dierking, 2000; Schauble et al., 1997). On the other hand, the trend in science exhibitions to include hands-on-exhibits reflects exhibition designers’ and curators’ focus on constructivist learning theories. Currently, these two theoretical approaches dominate research on learning within the context of science exhibitions. Existing advanced technologies in science exhibitions also reflect this trend, as can be seen in the number of advanced technologies supporting socio-cognitive conflicts, internalization of social processes, co-construction of knowledge, and active participation in knowledge building (cf. table 1). To gain a more complete picture of collaborative learning in science exhibitions, museum researchers must consider other mechanisms as well. Media designers should collaborate with learning researchers and base their design of advanced technologies on other identified mechanisms of learning as well.

An important step for the careful design of media applications is empirical examination and validation: Continuous formative evaluation of advanced technologies can validate assumptions about their learning potential and continuously improve their design (this approach is usually called “design-based research” (The Design-Based Research Collective, 2003). The iterative approach of media design is a promising way to support knowledge communication in science exhibitions by means of new technology. But an experimental approach can offer valuable information for enhancing learning in science exhibitions: We should first analyze the effect of advanced technologies on visitor-to-visitor knowledge communication in more detail. A major question for future research is which elements of advanced media applications are effective for the support of visitor-to-visitor knowledge communication and learning in science exhibitions.

Advanced technologies have been presented in this chapter that elicit, support or even only enable visitor-to-visitor knowledge communication in or beyond groups, as well as advanced media applications that act as platforms for knowledge communication (in and beyond the actual museum site). This review both contributes to our understanding of (collaborative) learning in science exhibitions through knowledge communication and provides valuable information for the design of advanced technologies. Prospective research should focus on the interdependence of advanced media applications, specific learning (and teaching) goals, the learning content, and learning activities and processes in science exhibitions. Addressing the question of *which* advanced media applications to implement for *which* purpose is still one of the major challenges for this field. The present systematic discussion will hopefully bring us one step further in this process.

2 Part II: A Discussion Terminal as Support for Deliberate Opinion Formation at Science Museums

We think so because other
people all think so; or because
after all we do think so; or because we
were told so, and think we must think so;
or because we once thought so,
and think we still think so; or
because, having thought so,
we think we will think so…
(Henry Sidgwick)

2.1 Opinion Formation about Socio-Scientific Issues

In the following, the analytical considerations on the potential of advanced media applications to support learning in science exhibitions presented in Chapter 1 will be applied to investigate the potential of discussion-based media installations for communicating contemporary science topics at science museums. For this purpose, the specific challenge of presenting the ambivalence and controversy of current science issues will be discussed prior to the identification of specific design requirements for a media application that explicitly supports opinion formation and reflective judgement at science museums.

2.1.1 Communicating Contemporary Science at Science Museums

In addressing current science topics like nanotechnology, the challenge for science museums is to both present the ambiguity and controversy of these topics in science exhibitions and to support visitors in formation of sophisticated opinions (Cameron, 2003; McLean, 2006). Presentation of multiple viewpoints from different perspectives is considered to be crucial for this purpose (Bayrhuber, 2001). Boyd (1999, p. 214) even refers to the modern science museum as a “marketplace of multiple points of view, a forum where controversy can be aired”. However, museums also might place visitors into the centre of the debate by giving them a voice of their own (Cameron 2003; Gammon & Mazda, 2000).

To ‘give visitors their own voice’ and provide spaces for dialogue and debate, not only face-to-face discussions (e.g., DECIDE, Duensing & Lorenzet, 2007) but also discussion-based computer terminals might provide valuable learning opportunities within the context of exhibitions about socio-scientific issues. Indeed, there is a major trend in science museums to offer spaces for dialogue where visitors have the opportunity to engage in discussion with other visitors (Knipfer et al., 2007): By means of discussion forums (on museums’ websites but also within the context of their exhibitions), museum visitors are encouraged to engage in public debate and leave their own opinion where it can be retrieved by other visitors later on. Also, reading through others’ statements gives rise to further reflection of one’s own opinion and this might augment one’s preliminary understanding - as it was argued in Chapter 1 already. To identify crucial design requirements for a discussion-based media application, I refer to educational theories in the following. Informal reasoning, critical thinking and reflective judgement are thereby considered as central concepts for unlocking the challenges of opinion formation on contemporary science topics.

2.1.2 Informal Reasoning, Critical Thinking and Reflective Judgement

To form their own opinions facing opposing arguments from multiple perspectives, people have to “rely on informal reasoning to bring clarity to the controversial decision they face” (Sadler, 2004a, p. 515). I concur with Zohar and Nemet (2002) who define informal reasoning as “reasoning about causes and consequences and about advantages and disadvantages, or pros and cons, of particular propositions or decision alternatives”. People arrive at reflective judgements - as a major outcome of informal reasoning about socio-scientific issues - by evaluating existing opinions and relevant information, and also by entertaining the sheer notion that the problem needs further evaluation. King and Kitchener's Reflective Judgement Model (1994, p. 13) describes the development of "the ability to evaluate knowledge claims and to explain and defend their points of view on controversial issues".

Informal reasoning in contrast to formal reasoning does not follow deductive logic or statistical inference stringently (Furlong, 1993). Rather, people draw inferences from uncertain premises and with varying degrees of confidence (Over & Evans, 2003). Additionally, informal reasoning tasks are often ill-structured and ill-defined, in the sense that there is rarely a correct answer or solution (Evans & Thompson, 2004). People come to conclusions with a certain degree of confidence, and these conclusions might be easily changed in the light of new evidence or additional information (Evans, 2005). But similar to formal reasoning, evaluation of pro and con arguments is a crucial activity in informal reasoning (Ennis, 1991; Halpern, 2003). Evaluation of arguments is regarded as a major skill of *critical thinking* (Facione, 1990):

> Critical thinking is essential as a tool of inquiry. As such, CT is a liberating force in education and a powerful resource in one's personal and civic life. While not synonymous with good thinking, CT is habitually inquisitive, well-informed, trustful of reason, open-minded, flexible, fair-minded in evaluation, honest in facing personal biases, prudent in making judgments, willing to reconsider, clear about issues, orderly in complex matters, diligent in seeking relevant information, reasonable in the selection of criteria, focused in inquiry, and persistent in seeking results which are as precise at the subject and circumstances of inquiry permit. (p. 2)

Critical thinking skills can be regarded as one basic pre-requisite for systematic and deliberate information processing (Griffin, Neuwirth, Giese, & Dunwoody, 2002) and are therefore essential for reflective judgment. Key characteristics of sophisticated opinions, which are based on use of critical thinking, are a) awareness of controversy as a pre-requisite for critical thinking, b) knowledge about both factual information and c) pro and con arguments from multiple perspectives (argument repertoire), d) integration of controversial arguments into a judgement that takes pro and con arguments into account and that is independent from prior beliefs or attitudes, e) a clear statement of one's own opinion and the rationale behind it, and f) respect for differing viewpoints about nanotechnology (cf. the proposed outcomes of the teaching of controversial issues by Oulton et al., 2004).

However, a common finding from studies investigating both formal (e.g., Nickerson, 1998; Stanovich & West, 1997) and informal reasoning (e.g., Keck, 1998; Scholderer, 2004) is that people heavily rely on prior attitudes when asked to judge a specific topic (*belief bias*, Klaczynski, 1997; *confirmation bias*, Nickerson, 1998). This often results in inadequate, unsophisticated attitudes because specific argumentation is not considered. This in turn leads to the fact that, when asked to give reasons for their personal opinion, people usually are not able to generate sound arguments to support their position (Kuhn, 1991). The dependence of a judgement on prior beliefs and prior attitudes is considered as a key indicator for suboptimal informal reasoning and lack of critical thinking (West, Toplak, & Stanovich, in press).

Former research also revealed that people usually are not able to provide objections to their own position (Shaw, 1996): *Myside bias* is the often mentioned phenomenon according to which people generate arguments in favour of their own position but fail to provide arguments for differing positions (Perkins, 1989). Integration of counterpositions to one's own judgement and a low myside bias in argumentation can be regarded as key indicators of deliberate opinion formation and reflective judgement (cf. Baron 1995/2003; Toplak & Stanovich, 2003). Fostering reflective judgement and deliberate opinion formation in turn is one of the major aims of the presented research as expression of well-founded and sophisticated opinions would be a prerequisite to benefit from discussion and debate.

In general, critical thinking skills and the individual disposition towards critical thinking are considered to be open to educational influence, especially if the intervention is contextually bound (Brown, Collins, & Guduid, 1989). Simple exposure to information, however, was shown to be not effective in changing knowledge, attitudes, or behaviour (Kuhn, 2005). The most widely applied approach in formal education is directed towards an understanding of science behind issues along with the consequences to society (issues-based approach; Pedretti, 1999; Zeidler et al., 2005). This approach usually presents current scientific debates in their many facets to highlight their complexity and to make students aware of various motives and perspectives involved in the debate (e.g., Pedretti, 1997, 1999; Oulton et al., 2004). Moreover, peer interaction, classroom debate, and argumentation are assumed to improve critical thinking about controversial and complex issues (Halpern & Nummedal, 1995; Ratcliff, 1997). Expression of a personal opinion about a controversial topic requires elaboration of available information, analysis and restructuring of given information and organisation of this knowledge for the purpose of arriving at a defensible position. As active participation in debates involves not only determining what to say but how to say it, higher order thinking is elicited, which in turn results not only in the recall of presented information but also in the transformation of this information (Bereiter & Scardamalia, 1987a).

Furthermore, discussion and debate require considering multiple viewpoints and evaluating competing opinions. I propose controversy and disagreement as promoter of learning about controversial issues as dealing with counterpositions of other visitors has the potential to reduce the myside bias in deliberation and argumentation as will be explained in the following paragraphs. Encountering disagreement can foster careful consideration of counterpositions and therefore enhance deliberate opinion formation. This assumption will be further explained in the following chapter, drawing on theories of social comparison and social influence on individual judgement.

2.2 Disagreement and Controversy as Major Promoter of Deliberate Opinion Formation

Controversy and disagreement is considered to be a major facilitator of learning about controversial issues in the literature (e.g., Johnson & Johnson, 1979, 1993; Johnson, Johnson, & Smith, 2000; Smith, Johnson, & Johnson, 1984): Disagreement elicits intense discussion about the pros and cons and elaboration on encountered opposing views. Therefore, encountering disagreement has the potential to lead to transformation and restructuring of original individual positions (Leitão, 2000). This is one reason that classroom debate and controversy are central components of formal curricula today (e.g., Halpern & Nummedal, 1995; Kennedy, 2007; Ratcliff, 1997; Zohar & Nemet, 2002).

As explained in the introduction, modern science museums are challenged to present the ambiguity and ambivalence of contemporary science topics such as gene technology, climate change, and nanotechnology. In this informal context, too, dealing with different opinions can create “powerful learning opportunities, as the visitors struggle with multiple viewpoints and diverse value perspectives” (Pedretti, 2006, p. 30). Knowing the positions of others and the rationale behind them makes one aware of multiple perspectives and informs one about counterarguments to one’s own position. Both awareness of what other people think and some understanding why they think so can foster opinions that are more soundly reasoned by arguments both *pro* and *con*.

To identify the processes that underlie the potential of controversy and disagreement for enhancing reflective judgement, I will draw on theories from social and cognitive psychology in the following paragraphs.

2.2.1 Social Comparison of Opinions and Consequences of Disagreement

From social comparison theory, we know that people compare themselves with other people (Festinger, 1954; Suls, Martin, & Wheeler, 2002/2004). This is true for both rather objective information (like results of a knowledge test) but also for value-based information (like evaluative judgments and opinions). In the case of opinions, it was proposed that both *non-social* information (i.e., information about pros and cons, about positive and negative features) and *social* information (via referral to others' opinion) contribute to opinion formation. Social comparison is regarded as a major avenue of information generation in this case (Gerard & Orive, 1987). People refer to the opinions of others to establish opinion stability especially when objective means of verifying are not available and when there is uncertainty of the appropriate position (Areni, Ferrell, & Wilcox, 2000; Festinger, 1954, 1957). Thus, social comparison of opinions is triggered mainly by need for evaluation (whether we are right) and need for validation (that we are right; Goethals & Darley, 1977).

The extent to which people refer to others for the purpose of social comparison depends on individual predispositions, which have been referred to in former research as, for example, social comparison orientation (Gibbons & Buunck, 1999), attention to social comparison information (Bearden & Rose, 1990), or self-monitoring (Snyder, 1979). However, exploring the *pros* and *cons* of a controversial topic like nanotechnology and active expression of one's own position at a discussion terminal is assumed to induce a situation of high uncertainty where need for social comparison is elicited. Thus, it is likely that museum visitors need to evaluate their opinions by seeking whether other visitors agree or disagree. This need for social comparison might be so great that *implicit* social comparison of opinions will probably take place as long as explicit social comparison information is not available (Orive, 1988): Research shows that, in general, similar others are assumed to judge an object similarly, that is, we project our personal opinion on similar others to reduce uncertainty (*social projection*, Allport, 1924). This psychological mechanism accounts for the phenomenon of *false consensus* (e.g., Ross, Green, & House, 1977) which is well known in social psychological research: As long as we have no other information, we presume that similar others share our opinions.

Encountering disagreement would disconfirm this projection mechanism. Generally, violation of expectations leads initially to cognitive dissonance, especially when people are faced with a conflicting majority position of similar others (Matz & Wood, 2005). Cognitive dissonance is experienced as psychological discomfort (Elliot & Devine, 1994) and dissonance was therefore conceptualized as a fundamentally motivational state as people aim at reducing dissonance to alleviate psychological discomfort (Festinger, 1957; Piaget, 1985). Confrontation with disagreement "is likely to induce considerable issue-relevant cognitive activity" as it induces instability or dissonance in the cognitive system, which needs to be resolved quickly to reach confidence again (Mackie, 1987, p. 42; see also Lowry & Johnson, 1981). Disagreement should therefore trigger the search for causal explanation ("Why do they think so?").

2.2.2 Informational Social Influence on Individual Judgement

When realizing that their personal opinion is in disagreement with the majority's opinion, people are likely to change their opinion to reach consensus again. Theories of social influence hereby distinguish between two major forms of social influence on individual opinions, that is, normative and informational influence (Chaiken, 1987; Deutsch & Gerard, 1955; Kaplan & Miller, 1987): Normative influence occurs when people change their own opinion in the direction of others' opinion due to conformity pressure without further cognitive effort ("consensus implies correctness" heuristic, e.g., Chaiken, Liberman, & Eagly, 1989). Informational influence, in contrast, occurs when people accept the positions of others as valid and attend to their rationales. Here, change in opinion reflects thinking about others' arguments and careful consideration forced by challenging points of view.

Price, Nir, and Cappella (2006, p. 63) examined social influence in the context of online political discussion and found evidence for the assumption that "the effects on individual opinions appear to be informational in nature" and are not only based on majority-pressure procedures: Change in opinion was mediated by elaboration on other participants' arguments. Similar results have been found in an experimental study which aimed at differentiating effects of normative pressure from persuasive argumentation (Burnstein & Vinokur, 1975): Simple *knowledge* of others' choice did not directly influence individual choice shift but was mediated by reflection on reasons others might have for their different opinion. Thus, the information about the opinion of others acted as trigger for thinking about counterarguments. The more the study subjects reported on thinking about others' reasons the more they shifted towards their choice. These results led us to the assumption that social comparison of opinions has the potential to stimulate careful consideration of counterarguments to one's own position - which might eventually lead to a revision of one's own position towards a more sophisticated opinion that takes also possible counterpositions into account.

These points so far suggest that people seek social comparison information to evaluate and validate their opinion when asked to take a position on a controversial science topic. When encountering disagreement with other people's judgement, dissonance should be elicited (as we infer that others share our opinion as long as we have no other information; cf. Matz & Wood, 2005), and strategies to reduce cognitive dissonance should be triggered (Festinger, 1957). In the present research, I examined the potential of disagreement within the context of an exhibition about nanotechnology. This setting is considered to be a prototypical example for informal reasoning during which the learner must accomplish reflective judgement about a complex and controversial topic without further instruction or support. I argue that one of the major potentials of discussion-based installations within this context is raising the awareness that other people might disagree, stimulating elaboration on counterpositions, and supporting the integration of both mysided and othersided arguments into one's own opinion.

2.3 A Discussion Terminal Informed by Socio-Cognitive Theories

Bell (1997) suggests that implementation of technology has the potential to support individual cognitive activity and social interaction. In recent years, for example, a broad range of computer tools have been developed that aim at improving classroom debates on controversial issues (e.g., *SenseMaker*, Bell, 1997; *Convince Me*, Ranney, Schank, & Diehl, 1995; *CSILE*, Scardamalia & Bereiter, 1994; *Belvedere*, Suthers, Weiner, Conelly, & Paolucci, 1995). Also, argumentation scripts can effectively improve students' ability to generate arguments for and against conflicting scientific theories (Kollar, Fischer, & Slotta, 2005; Weinberger, Stegmann, Fischer, & Mandl, 2007). However, these studies focused on tools for supporting argument construction and collaborative debate in formal learning settings. Museum visitors, however, are faced with an *informal* reasoning task, namely to state a personal opinion about a socio-scientific issue. In informal settings, critical evaluation of presented pro and con arguments and integration of this controversial information into a well-founded opinion is even more challenging as people seldom are confronted with sound logical arguments (Shaw, 1996).

The presented research supposes that reflective judgement can be enhanced by means of computer support that addresses relevant activities which particularly encourage critical thinking. From the theoretical considerations so far, two relevant design requirements for computer-mediated discussion-based activities in the context of science museum exhibitions about socio-scientific issues can be derived, namely 1) the opportunity to become actively involved in the debate through expression of a personal opinion and 2) the salience of *pro* and *con* arguments from multiple perspectives and support for the critical evaluation of these arguments. Both factors should have a positive impact on individual opinion formation processes. Specifically, deliberate opinion formation based on the careful consideration of relevant and controversial information from various perspectives should be fostered, which would result in opinions that are independent from prior beliefs or attitudes.

For the purpose of this research project, a discussion terminal has been designed that directly addresses these two design requirements. The discussion terminal is integrated into an exhibition about nanotechnology and presents relevant arguments in the form of expert statements from four different application areas of nanotechnology. These expert statements have to be critically evaluated in terms of personal agreement and relevance. This ensures that the process of active opinion expression is based on single arguments before making an overall judgement about nanotechnology. Drawing on the research framework presented in Chapter 1 and on the theoretical considerations presented earlier in this chapter, a further potential of discussion terminals is the opportunity for opinion exchange and discussion among visitors. Socio-cognitive conflict elicited by disagreement among visitors and explanation and argumentation of a personal position to other visitors can be regarded as major learning mechanisms addressed by a discussion terminal. Feedback about others' opinion is promising with regard to deliberate opinion formation as existing disagreement among visitors is made salient. Disagreement should contribute to the process of integration of controversial arguments and counterpositions into one's own judgement and thus further enhance opinion formation.

In the following two chapters, the empirical investigation of a discussion terminal, which addresses all identified design requirements and learning potentials, will be described. The focus of the first study lay on the examination of the impact of the factors *active opinion expression* and *salience of arguments* for individual opinion formation. The second study then investigated the impact of *disagreement* among visitors on opinion formation and judgement.

3 Study 1: The Role of Active Opinion Expression and Salience of Arguments for Individual Opinion Formation

To every complex question there is
a simple answer and it's wrong…
(H.L. Mencken)

3.1 Research Questions and Hypotheses

In the first experimental study the impact of opinion expression and salience of arguments at the proposed discussion terminal on opinion quality was examined. It was assumed that both, salience of arguments and active expression of opinion, are crucial factors for deliberate opinion formation: The study participants should remember more arguments if the discussion terminal raises salience of arguments by providing the opportunity to deal with controversial pro and con arguments followed by the opportunity to write down one's own opinion. Additionally, they should not only recall arguments that support their own position but show a low myside bias in their argument repertoire, thus, having a balanced argument repertoire. Likewise, when asked to state their personal opinion and to give a rationale behind their position in an open statement after the museum visit, their statements should demonstrate higher levels of reflective judgement indicating well-founded and deliberate opinion formation.

Also, for participants who elaborate on relevant pro and con arguments at the discussion terminal before stating their own opinion, post-visit attitudes should be independent from prior attitudes. In contrast, it is assumed that participants who are not offered the chance to advance their own opinion at the discussion terminal will show a confirmation bias indicated by post-visit attitudes that are highly predictable according to their prior attitudes. The same result should be true for those who indeed state an opinion at the terminal but without salience of arguments beforehand.

3.2 Method

3.2.1 Research Design

A study was designed to investigate whether or not a discussion terminal supports deliberate opinion formation. In a 2x2 design (see table 2) the impact of opinion expression and salience of arguments on opinion quality was examined.

Table 2. Research Design Study 1

	Expression of a Personal Opinion	
Salience of Arguments	*no*	*yes*
no	n = 14	n = 16
yes	n = 16	n = 14

The study participants were randomly assigned to one of the four experimental conditions. Condition 1 participants worked on a quiz which asked for facts presented in the exhibition (control). In condition 2, for which salience of arguments was implemented but no personal opinion was expressed, participants assigned eight controversial statements to corresponding images of experts known from the exhibition by ‘drag and drop’ (salience of arguments only, see fig. 3). Condition 3 participants rated NT in general as either “I am in favour of” or “I am against” on a rating scale (ranging form -100 to +100) and expressed their own opinion by writing a short statement at the discussion terminal (opinion expression only, see fig. 3, bottom). The fourth group was provided with the same eight expert statements pro and con as in condition 2 but had to additionally evaluate these arguments with regard to personal ‘agreement’ and ‘relevance’ by means of rating scales before giving a general judgement (opinion expression and salience of arguments, see fig. 3).

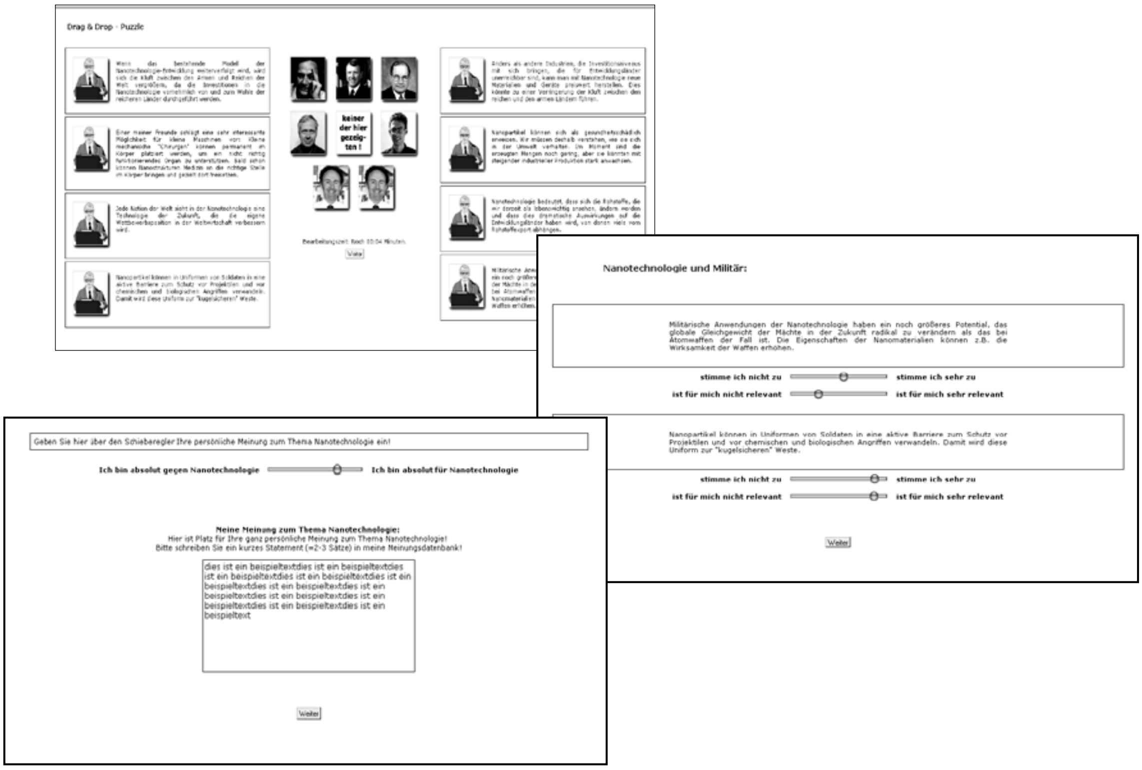

Figure 3. Salience of arguments without and with support for critical evaluation (condition 2 on top, condition 4 in the middle) and opinion expression with overall judgement and free statement (bottom, conditions 3 and 4)

3.2.2 Material

A virtual exhibition about nanotechnology (NT) was used as learning material which was based on a real exhibition (http://www.nanodialogue.org; see also the Appendix). The exhibition presented both facts about and objects of NT and information about chances and risks. NT is a contemporary socio-scientific issue on which opinion formation processes might easily be shaped by an exhibition in science museums: Studies assessing public opinion about NT showed that hardly anyone exactly knows what NT is, and extreme and strong prior attitudes towards NT are rare (e.g., Scheufele, 2005; Waldron, Spencer, & Batt, 2006). The exhibition was small but complex enough to serve as ideal “learning material” for this study.

3.2.3 Participants

64 students (25 male, 35 female) from the University of Tuebingen participated in the study for payment (55 % from social sciences and humanities, 40 % from natural sciences, 5 % others). They were recruited using leaflets distributed at students' halls of residences and email advertising. The average age (years) was $M = 25.93$ ($SD = 5.32$), ranging from $Min = 19$ to $Max = 41$.

3.2.4 Procedure

After filling in a short web-based questionnaire to assess their prior knowledge, prior attitudes, interest and motivation, and also Need for Cognition (Cacioppo & Petty, 1982) and Need to Evaluate (Jarvis & Petty, 1996), Ss explored the virtual exhibition at a personal computer for about 30 minutes without further instruction. Then, Ss were randomly assigned to one of the four experimental conditions. They completed a short quiz about NT, assigned eight statements to corresponding expert images by drag and drop, rated these eight statements by personal agreement and relevance, and/or generated an overall statement about NT. For both the quiz and the drag & drop tasks, they got feedback about their success. All tasks had a time-out of ten minutes to control for time on task (all subjects completed their tasks within this time). After that, all Ss filled in a post-questionnaire and were rewarded for participation. The overall duration of the experiment was approximately 90 minutes.

3.2.5 Measures

Pretest measures. Prior knowledge, prior attitudes, interest and issue involvement were assessed in advance of the museum visit (see Appendix for the questionnaires). Also, need for cognition was assessed with a German adaptation of the short Need for Cognition Scale (Cacioppo & Petty, 1982). A German adaptation of the Need to Evaluate Scale (Jarvis & Petty, 1996) was used to assess individual tendencies to engage in critical evaluation of information.

All dependent variables described below aim at specifying opinion quality after the exhibition visit and the activities at the discussion terminal. As pointed out in the theoretical considerations in Chapter 2, knowledge about relevant arguments *pro* and *con*, the ability to give a valid rationale of one's personal opinion, and the detachment of post-visit attitudes from prior attitudes are central indicators for deliberate opinion formation.

Argument repertoire. To assess attitude relevant knowledge, that is, relevant arguments for or against NT, Ss were instructed to list all arguments they could remember and to indicate by "+" and "-" whether it was a pro or con argument. From this list of arguments, measures have been derived for the a) overall sum of arguments, b) sum of pro and c) sum of con arguments, d) balance of argumentation, and e) sum of areas of application covered by recalled arguments.

Opinion quality. To assess opinion quality, Ss were asked to write an essay stating their opinion about NT and providing a rationale for their personal opinion. These summaries of participants' personal positions have been analyzed with regard to indicators of reflective judgement. For this purpose, the coding scheme presented in table 3 was established based on the reflective judgement model by King and Kitchener (1994) and the criteria from the Reflective Judgement Scoring of Christen, Angermeyer, Davison, and Anderson (1994).

Thirty essays out of 60 were coded by a second rater. The two raters completely or closely agreed - i.e., there was a difference of maximal one point - in 28 cases (93 %), and clearly disagreed only in 2 cases (7 %). The interrater reliability correlation (Spearman-Rho) was $r = .84$ ($p < .01$). The mean difference between the two raters' scores was $d = 0.20$ indicating that the two raters were comparably lenient/harsh in their scoring.

Table 3. Reflective Judgement Scoring Criteria

Score	Description
0	Statements that fail to express an own opinion were coded as 0, indicating a very low level of reflexivity. Statements of this level may cite arguments both pro and con nanotechnology but Ss make no attempt to evaluate these arguments or integrate them into an own position.
1	Statements that stated an opinion (however, this opinion can be pro or con but also neutral or ambivalent!) but provided no rationale at all were coded as 1. This level indicates that the Ss did not use the information of the exhibition or expert statements for expression of opinion.
2	Statements with rationale but without valid grounds for this rationale were coded as 2. Ss have made limited effort to use information and arguments from the exhibition to base their position. However, these rationales do not validly support their position or might be incoherent.
3	Statements with valid rationale but with clearly mysided argumentation and that therefore failed to integrate reasons for possible counter positions were coded as 3. These statements show that Ss did not realize that relevant arguments might result in multiple positions. Ss provide supporting arguments for their own position only. Evaluation of othersided arguments does not take place.
4	Statements with recognition and citation of counter positions but no rebuttals were coded as 4. These statements show that Ss were able to recognize that other positions may exist and to weigh both pros and cons of nanotechnology. However, a valid integration of counter positions into Ss' own opinion by means of rebuttals of counter arguments still lack in this level. Ss' own position might be supported by devaluation of the counterpositions.
5	Statements with careful rationale that evaluates both pro and cons, that shows significant recognition of counterpositions, and that incorporates also rebuttals and careful integration of counterpositions were coded as 5, finally. These statements are both comprehensible and persuasive expressions of an own position.

Attitudes. Ss post-visit attitudes towards NT were assessed by an attitude profile which contained 12 seven-point semantic differentials (e.g., good-bad, beneficial-harmful, secure-dangerous, etc.). After reliability analyses, item 4 was excluded (modern-old fashioned) from further analysis (item-scale correlation was r_{it} = .05). All other items reached the critical item-scale correlations of r_{it} > .30. Resulting Cronbach's alpha was α = .84. Means of the remaining eleven semantic differentials were calculated for each subject to assess post-visit attitudes towards NT.

Factual knowledge. Factual knowledge about NT was assessed by means of a short knowledge test containing twelve multiple choice questions about NT, ranging from simple factual knowledge to more transfer knowledge. Items scored as “1” point if the answer was correct; otherwise, items were scored as “0”. Then the sum of correct answers was calculated.

3.3 Results

Four subjects had to be excluded from further statistical analyses as they had already visited the exhibition in advance of the study. The following analyses are based on the remaining $n = 60$ study participants. The four conditions were comparable with regard to the assessed pre-test measures (all $p > .10$).

First, I would like to report on data gained at the discussion terminal itself before continuing with the results of the data analyses concerning the dependent variables: The mean overall judgement of Ss of conditions 3 and 4 ($n = 32$), who were asked to express their personal opinion about NT at the discussion terminal, was $M = 19.94$ ($SD = 43.11$) on a scale ranging from “-100” (i.e., very negative) to “+100” (i.e., very positive), indicating a ambivalent (or neutral) judgement of NT on average. The evaluations of the eight expert statements with regard to personal agreement and subjective relevance, which were gathered for all Ss of condition 4, are shown in table 4. The evaluation scale ranged from “-100” (absolutely disagree or totally irrelevant respectively) to “+100” (absolutely agree or very relevant respectively). The evaluation means indicate a very differential evaluation of *pro* and *con* arguments for the various application areas. The expert statements are shown in the Appendix.

Table 4. Evaluation of the Expert Statements at the Discussion Terminal (condition 4, *n* = 16)

	M	*SD*
Agreement: Society Pro	-42.75	53.90
Agreement: Society Con	64.38	39.04
Agreement: Medicine Pro	21.13	57.02
Agreement: Medicine Con	68.25	47.56
Agreement: Economy Pro	14.75	66.31
Agreement: Economy Con	2.69	59.90
Agreement: Military Pro	32.69	64.66
Agreement: Military Con	24.81	61.08
Relevance: Society Pro	25.25	55.20
Relevance: Society Con	43.25	40.29
Relevance: Medicine Pro	19.63	61.25
Relevance: Medicine Con	55.06	56.79
Relevance: Economy Pro	-3.44	62.63
Relevance: Economy Con	15.50	45.33
Relevance: Military Pro	-28.50	70.34
Relevance: Military Con	-15.19	70.62
Agreement: Pro (Mean)	6.45	28.79
Agreement: Con (Mean)	40.03	27.45
Relevance: Pro (Mean)	3.23	34.90
Relevance: Con (Mean)	24.66	28.93

In the following section, comparisons on the four experimental conditions with regard to indicators of deliberate opinion formation, namely the argument repertoire, opinion quality, and attitudes towards NT are reported. The four conditions have been also compared with regard to factual knowledge.

3.3.1 Argument Repertoire

Table 5. Descriptives for Argument Repertoire Indicators and Opinion Quality

Variable	(1) [a]		(2) [a]		(3) [b]		(4) [b]	
	M	(SD)	M	(SD)	M	(SD)	M	(SD)
Sum of *Pro* Arguments	2.64	(1.08)	2.21	(1.12)	2.25	(1.77)	2.44	(1.26)
Sum of *Con* Arguments	2.50	(1.65)	3.50	(2.07)	2.81	(2.29)	2.06	(1.24)
Total Number of Arguments	5.14	(2.28)	5.71	(2.70)	5.06	(3.80)	4.50	(2.16)
Balance of Argumentation	5.86	(1.10)	5.57	(1.83)	5.94	(1.18)	6.25	(1.07)
Total Number of Areas of Application	1.79	(1.05)	2.14	(1.41)	1.25	(1.13)	2.44	(1.32)
Reflective Judgement Score (Opinion Quality)	2.00	(1.40)	3.50	(0.76)	2.69	(1.40)	3.69	(0.63)

Note: (1) = Control, (2) = Salience of Arguments only, (3) = Opinion Expression only, (4) = Salience of Arguments and Opinion Expression

[a] $n = 14$. [b] $n = 16$

Means and standard deviations for all argument repertoire indicators for the four conditions are shown in table 5. To test the assumption that expression of opinion and salience of arguments both lead to a larger and more balanced argument repertoire compared to Ss of the control condition, the four conditions have been compared with respect to the argument repertoire measures: Results are shown in table 6. The performed MANOVA revealed a significant main effect for salience of arguments and a significant interaction effect of opinion expression and salience of arguments. The main effect for opinion expression was not significant, however. Contrasts have been calculated to identify significant group mean differences indicated by the overall multivariate test with condition 4 as reference group. There was a significant difference between conditions 2 and 4, in favour of condition 2, with regard to number of recalled con arguments ($\psi = 1.52$, $p < .05$, Cohen's $d = 0.84$), and a significant difference between conditions 3 and 4, in favour of condition 4, concerning number of application areas ($\psi = -1.15$, $p < .01$, Cohen's $d = 0.96$).

On a descriptive level, a tendency for a more balanced argumentation for Ss of condition 4 could be observed (*M* = 6.26 at a 7-point scale with “7” indicating perfect balance, *SD* = 1.07) compared to Ss of the three other conditions (means ranging from 5.53 to 5.92).

These results indicate that participants who dealt again with relevant arguments at the discussion terminal did not necessarily have a larger argument repertoire but a broader argument repertoire as they gave arguments from significantly more areas of argumentation. Ss of condition 2 who worked on a drag & drop-quiz and were not supported in critical evaluation of arguments recalled more con arguments than Ss of condition 4 who additionally had to critically evaluate these arguments.

Table 6. Multivariate Analysis of Variance for Argument Repertoire Indicators (GLM)

Source	df	F	η^2	p
Opinion Expression	5	0.92	.08	.47
Salience of Arguments	5	2.53*	.19	.04
Opinion Expression* Salience of Arguments	5	3.21**	.24	.01
error	52			

*p < .05. **p < .01.

3.3.2 Opinion Quality

On average, Ss’ essays on their own opinion about nanotechnology reflected a moderate level of reflective judgement (see table 5). This indicates that participants were able to express a personal opinion and give a valid rationale but failed to integrate counterpositions and showed a mysided argumentation in their essay (see the reflective judgement scoring criteria shown in table 3).

To examine the hypothesis that expression of opinion and salience of arguments only in combination lead to a higher opinion quality, the four conditions have been compared with regard to the assigned reflective judgement scores by means of an ANOVA. Results are shown in table 7. A highly significant main effect of salience of arguments was revealed. Neither was the effect of opinion expression significant nor an interaction effect of both factors was found. However a simple contrast between condition 1 (control) and condition 4 (expression of opinion and salience of arguments) was significant ($\psi = 1.34$; $p < .05$, Cohen's $d = 1.55$). Also, the contrast between condition 3 (opinion expression only) and 4 was significant ($\psi = 1.01$, $p < .05$, Cohen's $d = 0.92$). This means that Ss of condition 4 reached significantly higher levels of reflective judgement compared to Ss of condition 1 and Ss of condition 3.

Table 7. Analysis of Variance for Opinion Quality (*n* = 57)

Source	df	F	η^2	p
Opinion Expression	5	2.21	.04	.14
Salience of Arguments	5	17.93**	.25	.00
Opinion Expression* Salience of Arguments	5	0.70	.01	.41
error	53			

Note. Three Ss did not properly write down an opinion statement and were therefore excluded from the analyses concerning opinion quality. The following results are based on the remaining *n* = 57.
*p < .05. **p < .01.

The results regarding Ss' opinion quality showed that salience of arguments was crucial for reflective judgement of NT. When the scores were compared in separate contrasts, condition 4 participants reached the highest levels of reflective judgement compared to condition 1 (control) and condition 3 (opinion expression only).

3.3.3 Attitudes

Ss' prior attitudes were slightly positive towards NT (*M* = 3.48, *SD* = 0.68 on a 5-point scale with "5" = very positive) but Ss were rather unconfident about their prior attitudes as expected (M = 2.08, SD = 1.24 on a 5-point scale with "5" = very confident).

After the exhibition exploration, NT was judged *M* = 3.78 (*SD* = 0.85) at a 7-point scale ranging from "*1*" = very negative to "*7*" = very positive in the posttest. No differences in Ss' post-visit attitudes towards NT could be found in an ANOVA, $F(3, 56) = 1.17$, $p = .33$. The hypothesis that salience of arguments is crucial for attitudes towards NT, that are independent from prior attitudes, was examined by means of a multiple regression analysis, with additional interaction term for prior attitudes * salience of arguments as predictor (cf. Aiken & West, 1991, p. 116; Pedhazur, 1997, p. 562). Results are shown in table 8. Prior attitudes and salience of arguments were significant predictors of post-visit attitudes. Expression of a personal opinion was no significant predictor, however. The interaction term prior attitudes * salience of arguments significantly predicted post-visit attitudes. This confirms the hypothesis of an interaction of prior attitudes and salience of arguments on post-visit attitudes towards NT.

Table 8. Summary of Regression Analysis for Variables Predicting Post-Visit Attitudes towards Nanotechnology (*n* = 60)

	B	SE B	β	T	p
Opinion Expression	-0.195	0.200	-0.115	-0.976	.333
Salience of Arguments	2.212	1.063	1.311*	2.082	.042
Prior Attitudes	0.774	0.196	0.615**	3.954	.000
Salience of Arguments* Prior Attitudes	-0.606	0.301	-1.261*	-2.016	.049

Note. $R^2 = .25$

*p < .05. **p < .01.

Figure 4 shows the regression of post-visit attitudes on prior attitudes separately for conditions without salience of arguments (i.e., 1 and 3) and for conditions with salience of arguments (i.e., 2 and 4): Only on condition of salience of arguments, Ss' post-visit attitudes were independent from their prior attitudes. In contrast, without salience of arguments, a strong relationship between prior attitudes and post-visit attitudes towards NT was revealed indicating belief bias in opinion formation.

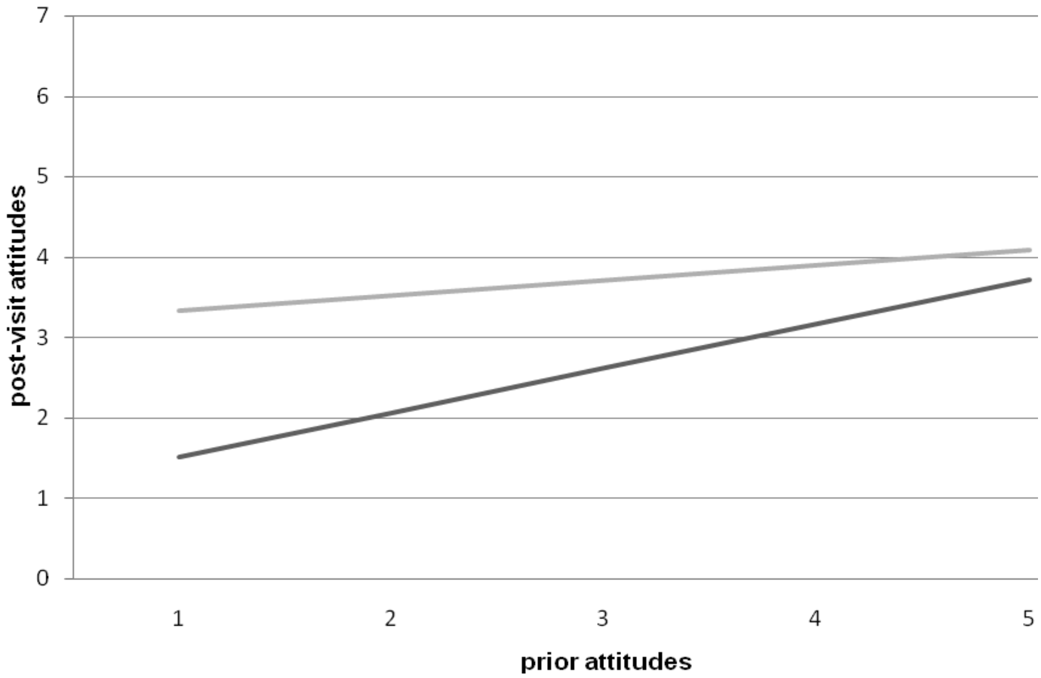

Figure 4. Linear regression of post-visit attitudes towards nanotechnology on prior attitudes in the condition of no salience of arguments (i.e., conditions 1 and 3; black) and in the condition of salience of arguments (i.e., conditions 2 and 4; grey)

3.3.4 Factual Knowledge

Mean of factual knowledge was M = 8.42 (SD = 2.36). An ANCOVA revealed no differences among the conditions, $F(3, 54) = 1.27$, $p = .29$. For this analysis, prior knowledge and duration of the museum visit were considered as covariates.

To sum up, upon measuring Ss' argument repertoire, a significant main effect of salience of arguments and an interaction effect of opinion expression and salience of arguments was revealed. Concerning opinion quality, salience of arguments was shown to be crucial for reaching high reflective judgement scores. When Ss' post-visit attitudes towards NT have been examined, it was revealed that Ss' attitudes after the museum visit were independent from prior attitudes only on condition of salience of arguments, namely for those who dealt with relevant pro and con arguments before advancing their personal opinion.

3.4 Discussion

In the presented study, the efficacy of a discussion terminal as support for deliberate opinion formation about NT was examined. Based on theoretical considerations and former research on teaching controversial socio-scientific issues, it was assumed that both opportunity to express one's personal opinion at a discussion terminal and the salience of arguments are crucial factors for deliberate opinion formation.

The hypothesis that salience of arguments is indispensable for formation of well-founded opinions was supported by the results. As it is known from research, people often show limited or disorganized elaboration to support their opinion (Greenwald, Persky, Campbell, & Mazzeo, 1999). In the presented study, Ss were able to provide a broad and balanced argument repertoire only in the condition of salience of arguments. It might be argued that the repeated presentation of relevant expert statements (i.e., arguments pro and con) at the discussion terminal in conditions 2 and 4 might have facilitated the recall of arguments in the post-test. However, it is noticeable that salience of arguments had no effect on the total number of arguments recalled. Ss of conditions 1 and 3 also recall a similar or even larger number of pro and con arguments (cf. table 5). Additionally, the mean reflective judgement score for the Ss' essays was significantly higher in the condition of salience of arguments compared to people of the control group, and also compared to participants who advanced an overall personal opinion at the discussion terminal. Those participants who dealt with relevant arguments at the discussion terminal were enabled to express a well-founded opinion and an adequate rationale in support of their own position. The results concerning the argument repertoire and reflective judgement both indicate elaboration processes that go beyond simple recall of presented arguments pro or con nanotechnology.

With regard to Ss' post-visit attitudes, salience of arguments was found to be necessary to make post-visit attitudes towards NT independent from prior attitudes. Research has shown that the evaluation of arguments and the resulting judgments are formed in a biased mode favouring information that is consistent to one's prior beliefs or knowledge (belief bias, e.g., Evans, Over, & Manktelow, 1993). Likewise, attitude research has shown that pre-existing attitudes serve as a judgmental anchor during evaluation of a new object or concept (e.g., Fiske & Neuberg, 1990), especially when people lack personal experience with the object/concept and relevant knowledge. This was the case in the presented study (e.g., Ss' prior knowledge was quite low, 20 % had never heard about nanotechnology before). This "top-down" process of attitude formation often results in inadequate attitudes that are not based on valid information about the attitude object. In this study however, the increased salience of arguments triggered critical thinking and evaluation of arguments that was independent from prior attitudes. This independence is considered to be a major indicator of good informal reasoning (Stanovich & West, 1997) and critical thinking (West et al., in press).

With regard to the research question how the opportunity to express a personal opinion impacts deliberate opinion formation, the presented study revealed that expression of opinion is helpful with regard to Ss' argument repertoire but not sufficient for formation of high-quality opinions. Assessment of the Ss' personal opinions in their written essays revealed that expression of opinion did not significantly enhance the Ss' opinion quality. One reason for lack of significant impact of expression of a personal opinion might be the fact that the used exhibition “Nanodialogue” was explicitly designed to elicit intense reflection on NT (see also http://www.nanodialogue.org for further information). For this purpose, multiple expert statements were presented that were highly controversial and represented multiple perspectives on NT. It is likely that this exhibition itself might have triggered evaluation and judgmental processes. The manipulation of offering a chance to express a personal opinion at the discussion terminal in this already evaluative setting might therefore not have been as effective as it would be in a more traditional science exhibition. This assumption should be further investigated in future studies.

Another interesting result in the presented study was that factual knowledge was not related to indicators of opinion quality, in contrast to former research which has shown that content knowledge is related to good informal reasoning about socio-scientific issues (Sadler & Zeidler, 2005). In the present research, however, knowledge acquisition did not affect deliberate opinion formation. I cannot rule out the possibility that content knowledge indeed is necessary for deliberate opinion formation but, in the light of the study results, content knowledge is obviously not in and of itself sufficient for good informal reasoning (this is in line with a main assumption of Kuhn, 1991).

The results imply that salience of arguments is important for deliberate opinion formation about contemporary socio-scientific issues. However, one might worry about negative effects of salience of arguments, too: From research on attitude formation, it is known that dealing with controversial arguments leads to higher levels of perceived ambivalence and lower levels of confidence with regard to opinion expression (Broemer, 1998; Van Harreveld et al., 2004). This can result in negative emotions, frustration, and in the end, negative attitudes (negativity bias of ambivalent attitudes, Cacioppo, Gardner, & Berntson, 1997). To ensure that this negative effect was not elicited in the presented study, subjective measures of opinion formation have been assessed: All Ss who were requested to express their own opinion at the discussion terminal were also asked to fill in a short questionnaire with 5-point rating scales to assess perceived ambivalence, perceived difficulty in forming an opinion about NT, and subjective opinion certainty. Perceived ambivalence, perceived difficulty of opinion formation, and opinion certainty were all moderate (2.50 to 3.25 on five-point Likert scales). Salience of arguments had neither an effect on perceived ambivalence, nor on perceived difficulty or on opinion certainty. These results indicate that salience of arguments, which aimed at raising awareness of controversy, did not result in negative emotions. Furthermore, the results concerning post-visit attitudes showed that there were no group differences between conditions with and without salience of arguments: Salience of arguments did not result in more negative attitudes. I conclude from these results that a discussion-based media application has been successfully designed that elicits further elaboration on controversial arguments without triggering negative effects on a subjective level which could generate negative attitudes.

To summarize the results of the first study, expression of opinion was revealed to have an impact on the argument repertoire but was not sufficient for formation of high-quality opinions. Salience of arguments was shown to be crucial for formation of well-founded opinions and attitudes that are independent from prior attitudes. However, the Ss still showed a *myside bias* in their essays on their personal opinion, that is, they were indeed enabled to generate a valid rationale to support their personal opinion but failed to integrate counterarguments and arguments to refute these counterarguments. This ability, however, is considered as major indicator for good informal reasoning and critical thinking (Kuhn, 2007).

The theoretical considerations in Chapter 2 aimed at specifying the potential of discussion-based installations to reduce the myside bias in judgement and therefore to further enhance critical thinking and reflective judgement. Encountering disagreement at the discussion terminal was proposed to be a major promoter of critical thinking and reflective judgement about a controversial scientific issue. In the following chapter, the empirical investigation of the impact of feedback about others' opinion on individual judgement will be described. I will present results that suppose that disagreement among visitors can successfully reduce the myside bias in argumentation and foster reflective judgement on contemporary science topics.

4 Study 2: Disagreement among Visitors as Major Promoter of Deliberate Opinion Formation

We are all tolerant enough of those
who do not agree with us,
provided only they are sufficiently miserable.
(David Grayson)

4.1 Research Questions and Hypotheses

To test the assumption that encountering disagreement at a discussion terminal after individual expression of a personal opinion would stimulate elaboration on and careful consideration of counterpositions and therefore lead to more sophisticated opinions, I conducted an experimental study in which the feedback about the opinion of others was manipulated. I asked museum visitors to state their personal opinion after exploration of an exhibition about nanotechnology. After expressing their individual opinion, they received feedback about others' average rating. This feedback was either consistent with the participant's own opinion or it was conflicting, that is, it showed clear disagreement with the average opinion of others. A third group received no feedback at all. The effect of disagreement on size and broadness of the participants' repertoire of arguments, on opinion quality measures, and on their attitudes towards nanotechnology was examined.

It was assumed that disagreement among visitors is beneficial for formation of opinions about nanotechnology that reflect and take othersided arguments into account. Based on the theoretical considerations explained above, it can be assumed that disagreement should lead to a reduction of myside bias in argumentation, that is, subjects encountering disagreement should not only recall arguments that support their own position but also a similar amount of othersided arguments. Likewise, when asked to state their personal opinion about nanotechnology and to give the rationale behind their position after the museum visit, their essays should demonstrate higher levels of reflective judgement indicating well-founded and deliberate opinion formation that incorporates counterarguments. When asked to discuss reasons why other people might disagree with their personal opinion, Ss who encountered disagreement should be able to construct valid counterarguments, to evaluate these arguments, and to refute their personal opinion against these counterarguments successfully. Concerning the overall judgement of nanotechnology after the museum visit, shifts in judgement will also be examined: Ss who encountered disagreement after their initial judgement should be more likely to change their judgement after feedback in favour of the majority opinion compared to the other conditions.

4.2 Method

4.2.1 Research Design

A computer-based study was designed to investigate whether disagreement supports deliberate opinion formation. Three conditions were compared with regard to size and broadness of participants' argument repertoire, to opinion quality measures, and to their attitudes towards nanotechnology: Condition 1 participants received *no feedback* after stating their personal opinion about nanotechnology (n = 22). In condition 2, participants received feedback that, on average, the other visitors *agree* with their own personal opinion (n = 20). Three statements that expressed *consistent* opinions (framed as three statements typed in by three visitors who explored the exhibition prior to the participant's own museum visit) were also provided. Condition 3 participants received feedback that, on average, the other visitors *disagree* with their own personal opinion (n = 19). Three statements that expressed *conflicting* opinions (again framed as three statements typed in by three visitors who explored the exhibition prior to the participant's own museum visit) were provided.

Figure 5 shows a screenshot visualizing disagreement between Ss' own position and the average position of the other visitors (condition 3).

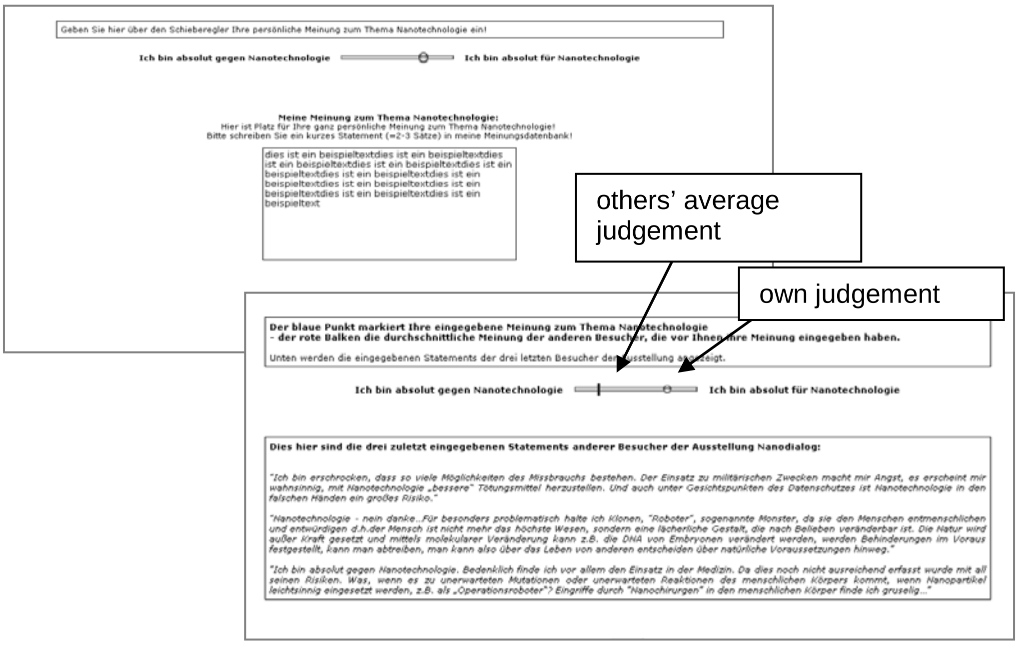

Figure 5. Interface to state one's personal opinion on the overall judgement scale and to write down a short statement (top), and screenshot showing Ss' own overall judgement being in disagreement with others' average judgement plus three exemplary statements of other visitors who disagreed (example of one Ss of condition 3, bottom).

In both feedback conditions (2 and 3), the feedback about others' opinion was faked and manipulated depending on how the subjects rated nanotechnology in their overall judgement. For this purpose, depending on both the condition (agreement versus disagreement) and the Ss' overall rating of nanotechnology, an algorithm selected one of three (faked) average ratings framed as the overall judgement of other Ss who visited the exhibition before.

4.2.2 Material

The same virtual exhibition about nanotechnology as in study I was used (see Chapter 3 and Appendix). Nanotechnology is a contemporary socio-scientific issue on which opinion formation processes might easily be shaped by an exhibition in science museums: Studies assessing public opinion about nanotechnology showed that hardly anyone exactly knows what nanotechnology is, and extreme and strong prior attitudes towards nanotechnology are rare (e.g., Scheufele, 2005; Waldron, Spencer, & Batt, 2006). Need for social comparison should therefore be high when asked to state a personal opinion about nanotechnology.

4.2.3 Participants

Participants were recruited using leaflets distributed at student dormitories and email advertising. 61 students (18 male, 43 female) of the University of Tuebingen participated in the study for payment (approx. 55 % from social sciences and humanities, 40 % from natural sciences, 5 % others). The average age (years) was $M = 25.66$ ($SD = 4.05$).

4.2.4 Procedure

At the beginning, participants filled in a short web-based questionnaire. Then they explored the virtual exhibition for 30 minutes at a personal computer. After exploration of the exhibition, Ss were asked to take a personal position towards nanotechnology and to answer a short questionnaire concerning their opinion expression. From this point on, the procedure differed depending on the experimental condition Ss had been randomly assigned to at the beginning of the study: Ss were given either consistent feedback or conflicting feedback, or they received no feedback at all. Ss who received feedback about the opinion of others filled in a short questionnaire to assess variables concerning the feedback. Then Ss had the opportunity to change their judgement about nanotechnology if they wished. At the very end, all Ss filled in a post-questionnaire, were informed about the manipulation and the aims of the study, and were rewarded for participation. The overall duration of the experiment was approximately 90 minutes.

4.2.5 Measures

Pretest measures. As in study I, prior knowledge, prior attitudes, interest and issue involvement were assessed in advance of the museum visit (see Appendix for the questionnaire). Also, need for cognition (Cacioppo & Petty, 1982), social comparison orientation (Gibbons & Buunk, 1999), and other-directedness in social situations (a central dimension of self-monitoring, Snyder, 1974; for the German scale see von Collani & Stürmer, 2003) were assessed with German adaptations of the original scales to assess individual tendencies to engage in social comparison processes and evaluation of social comparison information.

Overall judgement and opinion change. Ss were asked to indicate their positions towards nanotechnology by means of a rating scale ranging from "*-100*" ("I am totally against nanotechnology") to "*+100*" ("I am absolutely for nanotechnology") and to write down a short statement indicating their position. Ss gave their overall judgement twice during the study, namely before and after feedback about others' opinion was provided (also, Ss of condition 1, who received no feedback, expressed their opinion again after a short pause).

Items for the manipulation check. After their first opinion expression, Ss answered a short questionnaire to assess their need for social comparison (*Would you like to learn about others' judgements*?), self generated consensus (*Guess how many of the other visitors share your opinion: 0%, 25%, 50%, 75%, or 100%*), and social projection of their personal opinion (*Please indicate your agreement on a 5-point Likert scale for the following statement: In general, the other visitors came to the same conclusion like me.*). Ss who received feedback about others' opinion also answered items to assess perceived disagreement (*Please indicate your agreement on a 5-point Likert scale for the following statement: The other visitors came to a very different conclusion about* *nanotechnology compared to my own position*.) and experienced dissonance after the feedback (assessed by several items regarding subjective emotional experiences after the feedback, e.g., *When I learned about others' opinion, I felt… astonished, …disturbed, …uncomfortable*).

Argument repertoire. To assess attitude relevant knowledge, that is, relevant arguments for or against nanotechnology, Ss were instructed to list all arguments they could remember (*pro* and *con* arguments separately). From this list of arguments, I derived measures for the a) overall sum of arguments, b) sum of *pro* and sum of *con* arguments, c) sum of areas of application covered by recalled arguments for both *pro* and *con* arguments, and d) myside bias of argument repertoire. For calculation of myside bias, one item of the post-test (forced choice) assessed Ss' overall position towards nanotechnology ("Overall, are you *pro* or *con* nanotechnology?"). This allowed for the recoding of sum of *pro* and *con* arguments into sum of *mysided* (SMA) and *othersided* (SOA) arguments. Myside bias was then calculated as the ratio of mysided and othersided arguments by *SMA / SOA*. A myside bias < 1 indicates that Ss recalled more othersided arguments than mysided arguments, a myside bias = 1 indicates that there is no bias at all and Ss recalled as much mysided as othersided arguments, and a myside bias > 1 indicates that Ss recalled more mysided arguments than othersided arguments.

Opinion quality. To assess opinion quality, Ss were asked to write an essay stating their opinion about nanotechnology *and* providing a rationale for their personal opinion. These summaries of participants' personal opinions have been analyzed with regard to indicators of reflective judgement (see Chapter 3). Six statements could not be coded as Ss did not work on the task properly (off-topic commentaries or missing statements). 25 out of coded 55 statements were coded by a second rater. The two raters completely agreed in 21 cases, closely agreed in 24 of 25 cases (only 1 point difference) and clearly disagreed only in 3 cases (with 2 points difference). The interrater reliability (Spearman's Rho) was r_s = .88 (p < .001). The mean difference between the two raters' scores was d = 0.22 (M_1 = 3.02, SD_1 = 1.13; M_2 = 2.80, SD_2 = 1.19), indicating that the two raters were comparably lenient/harsh in their scoring.

Counterargument generation/rebuttal construction. This task was introduced for the purpose of the second study in addition to the opinion quality measures also used in study one (above): Ss were asked to generate three reasons why others might disagree with their position (i.e., counterarguments) and discuss these counterarguments for the purpose of defending their personal position (i.e., to construct rebuttals). Kuhn (1991) assumes that those who can generate counterarguments with respect to their own opinion and find a resolution in favour of their own opinion are at the highest levels of knowledge about the issue under discussion (Cappella, Price, & Nir, 2002). The ability to refute counterarguments is a measure of the depth of knowledge held. To assess quality of counterargument/rebuttal construction, a 6-point rating scale was developed (see table 9). Each counterargument/rebuttal construction was then coded and the sum of scores of the three single rebuttals was calculated for each participant. For 36 out of 61 Ss, rebuttals were coded by a second rater. The two raters completely or closely agreed - there was a difference of maximal one point - in 34 cases, and clearly disagreed only in 2 cases (with a difference of two points). The Spearman-Rho correlations ranged between r_s = .74 and r_s = .98 (all p < .001) for the three counterargument/rebuttal construction tasks. Similarly, the correlation for overall rebuttal scores (sum of the three single scores) of both raters was highly significant with r_s = .87 (p < .001).

Table 9. Counterargument Generation/Rebuttal Construction Scoring Criteria

Score	Scoring Criteria
0	Statements that fail to generate othersided arguments are coded as 0.
1	Statements that generate othersided arguments but fail to discuss them at all are coded as 1. Other perspectives are cited but no attempts to critically analyze and evaluate these positions and to defend the personal opinion against counterarguments are made.
2	Statements with limited reflection on others' views are coded as 2. However, these statements engage only othersided ideas that are obvious or agreeable. Avoids challenging or discomforting ideas. No evidence of attending to others' arguments critically. Superficial refutation of own position if any. No use of counterevidence. No evidence of self-assessment can be found.
3	Statements that yield emerging reflection on othersided arguments are coded as 3. Valid counterarguments are constructed and discussed. However, others' perspectives are treated superficially. Alternative views are dismissed hastily or treated in a way that understates the conflict. Statements tend to discriminate or devaluate other perspectives. No use of counterevidence to defend the own position. No evidence of self-assessment can be found.
4	Statements that show thoughtful reflection on othersided arguments are coded as 4. These statements engage challenging ideas and investigate others' arguments in a limited but thoughtful way. Evidence is used to successfully refute own position. Some evidence of reflection of own position and self-assessment. Limited integration of counterarguments into own position. Begins to relate alternative views to qualify own analysis.
5	Statements that show respectful analysis of others' arguments and thoughtful justification of own position are coded as 5. Clearly justifies own view while respecting views of others. Provides counterevidence to defend own position. Analysis of other position is nuanced and respectful. Clear evidence of reflection on own position and self-assessment. Integration of counterarguments into own position.

Attitudes. Ss post-visit attitudes towards nanotechnology were assessed by an attitude profile which contained 12 seven-point semantic differentials (e.g., good - bad, beneficial - harmful, secure - dangerous). After reliability analysis, I excluded item 4 (modern - old-fashioned) from further analysis (as item-scale correlation was $r_{it} < .30$). Resulting Cronbach's alpha was $\alpha = .83$. The mean of the remaining eleven semantic differentials was calculated for each subject to assess post-visit attitudes towards nanotechnology.

4.3 Results

First, I would like to report shortly on the data gathered at the discussion terminal itself, that is, the overall judgement of NT (all data refer to Ss' first opinion expression prior to feedback): On average, NT was judged M = 30.67 (SD = 37.37) on a rating scale ranging from "-100" (i.e., very negative) to "+100" (very positive) indicating a slightly positive evaluation of NT in general. N = 48 Ss rated NT positively (i.e., $X > 0$), the remaining n = 13 Ss rated NT negatively (i.e., $X < 0$). The most negative evaluation was Min = -73, the most positive evaluation was Max = 99.

The following comparisons focus on the impact of the social comparison information which was either consistent or conflicting with the subjects own opinion. Thus, if not indicated otherwise, the analyses are based on the overall sample of N = 61 subjects. An alpha level of .05 was used for all statistical tests. All conditions were comparable with regard to the assessed pre-test measures (all p >.10).

4.3.1 Manipulation Check

Need for social comparison after individual opinion expression was M = 3.90 (SD = 1.21) on a 5-point Likert-scale with "5" = very interested in others' judgement. 67 % of the Ss showed projection of their personal opinion as they expected that other visitors would have the same opinion as themselves, versus 33 % who assumed that others might hold a different opinion about nanotechnology. On a 5-point Likert scale to assess tendencies for self generation of consensus ("*1*" = 0% of the other visitors have the same opinion about nanotechnology to "*5*" = 100 % of the other visitors have the same opinion about nanotechnology), M = 3.20 (SD = 0.83) indicated that subjects tend to assume that more than half of the other visitors (approx. 60 %) share their personal opinion about nanotechnology. The three conditions did not differ in any of these variables (all p > .10).

To ensure that the manipulation of agreement vs. disagreement by means of the social comparison information after individual opinion expression was successful, I compared conditions 2 and 3 with regard to the mean perceived conflict between one's personal opinion and the average opinion of others. In condition 2, where consistent feedback was given, Ss reported low perceived conflict (M = 4.30, SD = 2.56 on a 10-point Likert-scale). In condition 3, where conflicting feedback was given, Ss reported high perceived conflict (M = 9.32, SD = 2.31). A separate groups T-test revealed that the mean perceived conflict differed significantly in conditions 2 and 3, $t(37) = -6.42$, $p < .001$, Cohen's $d = 2.06$. Also, a one-way MANOVA with measures of emotional and affective reactions following the feedback about other's opinion as dependent variables revealed significant differences between condition 2 and 3, $F(4, 34) = 10.96$, $p < .001$, $\eta^2 = .56$: Ss of the disagreement condition reported higher levels of astonishment ($p < .001$), a tendency for higher levels of disturbance ($p < .10$), and lower levels of comfort ($p < .05$) after feedback compared to the agreement condition.

4.3.2 Overall Judgement and Opinion Change

Table 10. Means and Standard Deviations for Dependent Measures

	No Feedback (1)[a]	Consistent Feedback (2)[b]	Conflicting Feedback (3)[c]
	M (SD)	*M (SD)*	*M (SD)*
Opinion Change	1.41 (7.90)	-4.50 (13.23)	-11.63 (24.05)
Argument Repertoire			
Sum of Pro Arguments	4.05 (1.89)	5.25 (1.92)	4.88 (2.12)
Sum of Con Arguments	3.45 (1.57)	3.50 (1.05)	3.94 (1.71)
Sum of Mysided Arguments	4.18 (1.92)	5.05 (1.82)	4.59 (1.92)
Sum of Othersided Arguments	3.32 (1.46)	3.70 (1.46)	4.24 (1.79)
Myside Bias	1.36 (0.36)	1.53 (0.72)	1.13 (0.45)
Opinion Quality	2.70 (0.87)	2.82 (1.38)	3.50 (1.10)
Counterargument Generation/ Rebuttal Construction	3.95 (3.03)	5.25 (3.01)	7.61 (2.36)
Attitudes towards NT	3.58 (0.84)	3.86 (0.64)	4.01 (0.82)

[a]n = 22. [b]n = 20, [c]n = 19

Means and standard deviations for opinion change are shown in table 10. Ss of condition 1 (control) and Ss of condition 2 (agreement) showed no shifts in overall judgement in a paired samples T-test, $t(21) = -.0.84$, $p = .41$ and $t(19) = 1.52$, $p = .15$. However, for Ss of condition 3 (disagreement), substantial and statistically significant shifts in Ss' overall judgement of nanotechnology were revealed, $t(18) = 2.11$, $p < .05$, Cohen's $d = 0.30$. To examine further whether or not this observed tendency for shift in overall judgement was in the direction of the majority opinion, I compared the mean difference of the overall judgements before and after feedback with the provided feedback rating for Ss of condition 3 (disagreement). The paired-samples T-test revealed that the mean distance has been substantially reduced by shifts in overall judgement, $t(19) = 5.32$, $p < .001$, Cohen's $d = 0.46$. That means that the observed mean shift in overall judgement was in the direction of the majority opinion.

These results so far suggest that Ss noticed and accepted the feedback about others' judgement. Ss who encountered disagreement experienced this feedback negatively (they were disturbed, astonished and felt less comfortable than Ss of the other conditions). After having received feedback, Ss of the disagreement condition were likely to change their opinion towards the majority opinion. To examine the hypothesis that this shift was not due to normative social influence but was based on consideration of others' reasons for their differing opinion, I compared the experimental conditions with regard to indicators of deliberate opinion formation, namely their argument repertoire, opinion quality, and counterargument/rebuttal construction.

4.3.3 Argument Repertoire

To test the assumption that disagreement leads to a *more balanced* argument repertoire and therefore a low myside bias, two a priori contrasts were performed to investigate differences in myside bias, namely a) whether myside bias in condition 3 (disagreement) was lower compared to conditions 1 and 2 combined (no feedback and agreement) and b) whether myside bias differed in conditions 1 and 2 (no feedback versus agreement). For the first contrast, the analysis revealed a statistically significant difference in myside bias, $t(43.757) = 2.08$, $p < .05$, indicating that Ss who encountered disagreement show a lower myside bias in their argument repertoire than Ss of the other two conditions combined (1 and 2). For the second contrast, the analysis revealed no significant difference in myside bias, $t(40) = 0.82$, $p = .42$, indicating that the myside bias did not differ between Ss who received no feedback and those who received consistent feedback. Means and standard deviations of myside bias are shown in table 10.

Regarding the other argument repertoire measures, the performed MANOVA revealed no significant effects of the experimental manipulation, $F(12, 104) = 0.88$, $p = .57$. Ss did not differ in sum of recalled pro or con arguments or in broadness of argument repertoire with regard to recalled application areas of nanotechnology. Also, sum of recalled mysided and othersided arguments did not differ between conditions. Means and standard deviations for all argument repertoire measures are shown in table 10.

4.3.4 Opinion Quality

On average, Ss' statements of their personal opinion about nanotechnology reflected a moderate level of reflective judgement ($M = 3.00$, $SD = 1.16$). This indicates that the study participants, on average, were able to express a personal opinion and give a valid rationale but failed to integrate counterpositions and showed a clearly mysided argumentation in their statement (cf. reflective judgement scoring criteria shown in Chapter 3, table 3). Means and standard deviations for the three conditions are shown in table 10.

A one-way ANOVA on the reflective judgement scores revealed a marginal effect for the factor *condition*, $F(2, 52) = 2.73$, $p < .10$, $\eta^2 = .10$. On the basis of this analysis, I performed two contrasts, namely a) whether opinion quality in condition 3 (disagreement) was higher compared to conditions 1 and 2 combined (no feedback and agreement) and b) whether opinion quality differed in conditions 1 and 2 (no feedback versus agreement). For the first contrast, the analysis revealed a statistically significant difference in opinion quality, $t(53) = -2.33$, $p < .05$, Cohen's $d = 0.64$, indicating that Ss who encountered disagreement show a higher opinion quality than Ss of the other two conditions combined (1 and 2). For the second contrast, the analysis revealed no significant difference in opinion quality, $t(35) = 0.33$, $p = .74$, indicating that opinion quality did not differ between Ss who received no feedback and those who received consistent feedback.

4.3.5 Counterargument Generation/Rebuttal Construction

On average, Ss wrote down two proper counterarguments and rebuttals ($M = 2.11$, $SD = 0.96$). Mean sum of the three single rebuttals scores was $M = 5.48$ ($SD = 3.17$) with a possible maximum of $M = 15$ (i.e., 5 + 5 + 5). A one-way ANOVA was performed on the sum of rebuttals scores. This analysis yielded a statistically significant difference between the three conditions, $F(2, 57) = 8.32$, $p < .01$, $\eta^2 = .23$. On the basis of this analysis, I performed two contrasts, namely a) whether quality of rebuttals in condition 3 (disagreement) was different compared to conditions 1 and 2 combined (no feedback and agreement) and b) whether rebuttal quality differed in conditions 1 and 2 (no feedback versus agreement). For the first contrast, the analysis revealed a statistically significant difference in quality of rebuttals, $t(58) = -3.76$, $p < .001$, Cohen's $d = 0.98$, indicating that Ss who encountered disagreement reached higher quality of rebuttals than Ss of the other two conditions combined (1 and 2). For the second contrast, the analysis revealed no significant difference in quality of rebuttals, $t(40) = 1.39$, $p = .17$, indicating that the quality of rebuttals did not differ between Ss who received no feedback and those who received consistent feedback. Means and standard deviations are shown in table 10.

4.3.6 Attitudes

In the posttest, the average attitude towards nanotechnology measured by means of the attitude profile was $M = 3.86$ ($SD = 1.77$) on a 7-point scale ranging from 1 = very negative to 7 = very positive. Means and standard deviations for the three conditions are provided in table 10. No differences in Ss' post-visit attitudes towards nanotechnology were found in a one-way ANOVA, $F(2, 58) = 1.17$, $p = .21$.

4.4 Discussion

In the present research, the potential of a discussion terminal within the context of an exhibition about nanotechnology was examined. I argued that encountering disagreement with other museum visitors after being asked to state a personal opinion would be beneficial for formation of opinions that reflect and take counterpositions into account. This was assumed to reduce the myside bias in argumentation and enhance the ability to generate counterarguments and successful rebuttals of these counterpositions. The results showed that participants who encountered disagreement by means of feedback about others' judgement after their opinion expression experienced this feedback negatively; they were disturbed, astonished and felt less comfortable than participants who did receive feedback about an agreeing majority or who did not receive feedback at all. These participants were also likely to change their opinion towards the majority opinion to reduce dissonance.

To examine the hypothesis that this shift was not due to normative social influence but was based on active consideration of others' reasons for their differing opinion, I compared the experimental conditions with regard to indicators of deliberate opinion formation. Disagreement was shown to reduce the myside bias in the participants' argument repertoire, that is, Ss who encountered disagreement recalled as much othersided arguments as mysided arguments, whereas Ss of the control and the agreement condition provided more supportive arguments than counterarguments to their position. Furthermore, disagreement led to higher scores in reflective judgement: Ss of the disagreement condition were able to state their personal opinion, to give a valid rationale, and to integrate and elaborate on counterarguments in their statements about nanotechnology. Quality of counterargument generation and rebuttal construction was also higher for Ss of the disagreement condition indicating that these participants indeed elaborated on the reasons why other people disagreed deliberately and were thereby enabled to construct valid rebuttals of the others' counterarguments.

A result I would also like to reflect on briefly is that I did not find any differences in post-visit attitudes. One might have expected that the psychological discomfort caused by cognitive dissonance had influenced people's attitudes towards nanotechnology negatively (*negativity bias*, Cacioppo et al., 1997). However, this was not the case in the present study: Groups did not differ in their attitudes towards nanotechnology. In fact, the disagreement condition reported slightly more positive attitudes towards nanotechnology compared to the other two conditions. I conclude from these results that I have successfully designed a discussion-based media application that elicits further elaboration on counterpositions and othersided arguments without generating negative attitudes towards the issue under discussion.

The reported results are consistent with prior findings of social psychological research. The effect of disagreement on dissonance experience, on dissonance reduction strategies and on attitude change was researched carefully during the last decades (Burnstein & Vinokur, 1975; Deutsch & Gerard, 1955; Doise, 1969; Kaplan & Miller, 1987; Kelley, 1952; Matz & Wood, 2005). In general, two major explanations have been considered to explain shifts in choice, namely *normative social influence*, which accounts for shifts mainly based on normative processes, and *persuasive argumentation, or informational social influence* respectively (cf. Burnstein & Vinokur, 1973, 1975). The reported effect of disagreement on opinion quality attained by the present study is consistent with the latter explanation of group influence on individual choice: The results provide support for the predictions derived from theories of informational social influence. First, Ss assumed that other people would share their personal opinion on nanotechnology as long as they had no other information which was predicted by theories of social projection of opinions (Orive, 1988). When encountering disagreement, their expectations were violated and psychological discomfort was experienced which is consistent with results of Matz and Wood (2005) and Orive (1988). Second, Ss who encountered disagreement changed their opinion towards the majority opinion to reduce discomfort as it is predicted by theories of social influence and attitude change (e.g., Mackie, 1987).

The results of the present study support the assumption of Burnstein et al. (e.g., Burnstein & Vinokur, 1973, 1975; Burnstein, Vinokur, & Trope, 1973) who suggested that such shifts in opinion are not due to normative pressure but are based on *informational* social influence: The study participants hold more sophisticated opinions that eventually reflect and take counterpositions into account. This indicates that the Ss elaborated on the reasons why other people disagree and integrated these counterarguments into their personal opinion. Moreover, Ss who encountered disagreement were enabled to generate more othersided arguments and to construct successful rebuttals of these counterarguments in the posttest. This ability was referred to as the third level of argumentative complexity by Kuhn (1991) who was the first to consider the ability to refute counterarguments as the most complex and sophisticated level of argumentative knowledge. This level of reasoning suggests a sophisticated knowledge about the issue under discussion as one does not only know reasons for one’s own position but also knows the counterpositions and refutations (Cappella et al., 2002).

Thinking from multiple points of view is often a standard for good reasoning that is stressed at higher levels of education (Kuhn, 2007). However, the “tendency to not give even-handed consideration to both sides of an issue” (Toplak & Stanovich, 2003, p. 858) has been found in numerous studies (Baron, 1995/2003; Klaczynski, 2000; Nussbaum & Kardash, 2005; Perkins, 1985; Stanovich & West, 1997; Toplak & Stanovich, 2003). This is mainly due to heuristic processing of information caused by the preference for evidence that will prove to be correct (*confirmation bias*, Nickerson, 1998). In this research however, the feedback that other people disagree apparently has provoked systematic processing of controversial information (cf. Mackie, 1987).

This conclusion must necessarily be tempered with regard to the particular conditions in which the influence of disagreement was studied here: First, in the present study, only intrapersonal strategies to reduce dissonance were available. However, strategies to reduce dissonance caused by disagreement other than reconsideration of the issue under discussion have been reported in former research, namely, discrimination of others opinion, refusal of others as a relevant reference group, forced compliance, influencing those who disagree to change their opinions, affiliating with others who agree, etc. (Nail, MacDonald, & Levy, 2000; Matz & Wood, 2005). Thus, different effects of disagreement must be assumed when examining scenarios other than the one used in the present study, for example, if there is face-to-face contact or (expectation of) follow-up interaction with other visitors who also stated a personal opinion at the discussion terminal, or if the discussion does not take place computer-mediated but as face-to-face debate. In such cases, identification, normative pressure and overt compliance with the majority’s position without further consideration of the issue also come into play (e.g., Mackie, 1987).

Second, in the present research, I decided to provide statements of other visitors together with the feedback about others’ judgement to give the participants the opportunity to think about the feedback. This is also more realistic in a real museum setting where museum visitors are allowed to state a personal opinion and to read through others statements, too. The reader should consider that this information was not new to the participants as the othersided arguments were also presented in the exhibition. This eliminates the alternative explanation that the effect of disagreement is due to the fact that the other conditions simply did not have the information about othersided arguments. However, the increased salience of counterarguments due to repeated presentation might also enhance simple recall of othersided arguments. The results concerning integration of counterarguments in their opinion statements and the rebuttal construction confute this hypothesis, however, as these tasks do involve more cognitive effort than simple recall of arguments. Specific information about others' reasons for an opposing view does not seem to be necessary at all as opinion shifts even occur without specific argumentation. This was attributed to some kind of "internal" argumentation by Burnstein and Vinokur (1975), that is, people seek explanations for disagreement and therefore elaborate on possible counterarguments challenging their own position triggered by the mere information that others disagree ("I wonder why they think so?"). Based on the research done by Burnstein et al., I assume that similar results might be observed if I only provided the information that other visitors disagree but no further information about their reasons.

To sum up, the present research brings together knowledge from social psychology and educational psychology to explain the potential of disagreement for learning about controversial topics and for deliberate opinion formation. It hence contributes to our understanding of individual informal learning about controversial issues and opinion formation processes - particularly because it focused on individual argumentation and opinion formation stimulated by others' judgement. Feedback about others' opinion and disagreement with others can be regarded as the main trigger for reflection on othersided arguments and other perspectives. And "what makes an opinion deliberate is not merely that it has been built upon careful contemplation, evidence, and supportive arguments, but also that it has grasped and taken into consideration the opposing view of others” (Price, Cappella, & Nir, 2002, p. 97). This is exactly what makes a discussion terminal within the context of an exhibition about contemporary science so valuable: Disagreement encountered at the discussion terminal was shown to enhance individual opinion formation and to reduce myside bias in argumentation substantially.

5 General Discussion

Education's purpose is
to replace an empty mind with an open one.
(Malcolm S. Forbes)

In this dissertation, the potential of advanced media applications for learning from science exhibitions was investigated. For this purpose, science exhibitions have been conceptualized as dynamic information spaces for knowledge building. Three pathways of knowledge communication have been proposed. It was argued that knowledge communication among visitors is a matter of particular importance for learning from science exhibitions. Therefore, several learning mechanisms have been discussed with regard to their relevance for visitor-to-visitor knowledge communication and collaborative learning. It was further argued that for the effective design of media applications as support for knowledge communication at science exhibitions, we must carefully examine the differential effects of media support and the underlying learning mechanisms. In this dissertation, the research framework was applied to answer the question how to support learning about contemporary science topics like nanotechnology: Discussion terminals have been proposed as innovative kind of discussion-based media installations for the communication of contemporary and controversial science topics as they can both support individual cognitive activity and address central mechanisms of collaborative learning.

Two empirical studies examined the potential of a discussion terminal as support for critical thinking and reflective judgement about nanotechnology. Specifically, three major factors have been investigated, namely a) active expression of a personal opinion, b) salience of arguments prior to opinion expression, and c) feedback about others' opinion.

The central finding of the first study was that salience of arguments was necessary to overcome the confirmation bias in opinion formation. Only when interacting with relevant arguments at the discussion terminal prior to opinion expression, the study subjects showed attitudes that were independent from prior attitudes; only then they were enabled to express well-founded opinions. Expression of a personal opinion was helpful with regard to Ss' argument repertoire but was not sufficient for the formation of sophisticated opinions.

However, a strong myside bias was still revealed in Ss' argumentation in the first study: The participants were able to provide a valid rationale for their personal position but failed to integrate counterarguments to, constraints of or rebuttals of potential counterpositions. The second study therefore focused on interventions that help to overcome the myside bias in opinion formation. It was argued that a major potential of discussion terminals is opinion exchange among visitors and that it makes disagreement and controversy aware. Therefore the impact of feedback about others' opinion after individual opinion expression was examined in the second study. Disagreement was shown to result in opinions that take counterpositions into account and that include successful rebuttals of counterarguments.

The results of both studies imply that a discussion terminal - when designed carefully - is a valuable facilitator of critical thinking and reflective judgement about contemporary science topics. Salience of arguments was shown to be necessary to support bottom-up formation of opinions independent from prior beliefs, and disagreement among visitors was shown to be efficient to reduce the myside bias in argumentation and to foster integration of possible counterarguments. Both a low confirmation bias and a low myside bias have been proposed as indicators of critical thinking and reflective judgement (Baron 1995/2003; Toplak & Stanovich, 2003; West et al., in press). I conclude from this, that the discussion terminal was successful in enhancing critical thinking and reflective judgement.

5.1 Generalizability of Results

The conclusions drawn from the results of the present studies must necessarily be tempered with regard to the particular conditions in which the influence of the factors opinion expression, salience of arguments and disagreement among visitors was researched here, namely, the selective sample of students and the rather formal situation of a laboratory experiment. Concerning the sample, I would like to argue that the sample of both studies is comparable to the audience of an exhibition on nanotechnology in a real museum setting: The exhibition “Nanodialogue”, which was used in this research, has already been evaluated by the University of Westminster (further information can be retrieved from http://nanodialogue.org). The target group for this exhibition was young adults with an average age of 30 (Amodio, 2007). And indeed, according to the evaluation report, that was based on questionnaires and data of about 800 visitors in eight European countries, visitors of this particular exhibition were predominantly young students (45 % under the age of 24) or highly-educated white collar workers who lived in urban areas (cf. http://www.wmin.ac.uk/sshl/page-1517). Therefore, a comparable and relevant sample was selected in the present study, and in turn, the knowledge gained can be carefully generalized to the expected target audience of an exhibition on contemporary science.

However, due to payment for participation and the rather formal situation of a laboratory experiment, the participants of this study might have invested more mental effort in exploration of the exhibition than museum visitors would normally do. This assumption has been partially supported by prior studies with another prototype of a discussion terminal (Deutsches Museum, Germany, cf. Haenle, 2008). On the other hand, the structural characteristics of a museum visit, namely, lack of educational goals, lack of learning guides or other direct instruction given prior to the exploration of the exhibition, lack of external monitoring or feedback on learning processes, and the therewith associated freedom of learning based on subjective interests are considered to be major characteristics of informal learning situations (Malcolm, Hodkinson, & Colley, 2003; Mayr, 2007). However, other influences than those focused on in this research might be significant for learning in a real museum setting. Thus, a replication of the results in a field study is currently planned to validate the results in a natural museum setting.

To conclude the discussion on generalizability of the results, it should again be pointed out that the present studies were conducted to examine the potential of a discussion terminal to support critical thinking and reflective judgement on a contemporary science topic and to identify major cognitive factors underlying this potential. With regard to these goals, the results of the present studies are valuable for both theory (what constitutes critical thinking and reflective judgement within the context of exhibitions on contemporary science) and practical considerations (how to scaffold visitors' opinion formation about controversial science topics).

5.2 Methodological Considerations

In this dissertation, I draw on knowledge from several areas of research that are related to opinion formation processes on (controversial) science topics to derive measures of opinion quality, namely from research on argumentation, on informal reasoning and critical thinking, and public opinion research.

The individual's *argument repertoire* was shown to be a reliable measure of public opinion quality by Cappella et al. (2002) and was also used in studies on informal reasoning before (e.g., Toplak & Stanovich, 2003). Knowledge about arguments from a broad range of perspectives and from both *pro* and *con* was shown to be effective for the assessment of public opinion quality. In the present dissertation, the subjects' argument repertoire was used to derive further quantitative measures for size and broadness of argumentative knowledge, for example, I calculated scores for sum of arguments pro nanotechnology, con nanotechnology, number of areas of application covered by recalled arguments, and balance of argumentation. It should be noted that these measures are quantitative in nature and allow only for limited interpretation with regard to people's opinion quality. They are first quantitative indicators of a person's opinion/attitude relevant knowledge. Others have also assessed the *quality* of single arguments using rating scales for relevance of an argument, its specificity, emotionality or distinctiveness (Zumbach & Reimann, 2006). But as one hardly finds any proper arguments (in the sense of Toulmin, 1958) in informal reasoning tasks, quantitative measures for Ss' argument repertoire seemed to be more valid for the purpose of in this dissertation.

A central dependent variable which was also calculated from Ss' argument repertoire for study 2, is *myside bias*. This measure has often been used in research on quality of informal reasoning (Baron, 1991, 1995/2003; Toplak & Stanovich, 2003). Usually, myside bias is calculated by subtracting number of othersided arguments from number of mysided arguments (e.g., Toplak & Stanovich, 2003). That would imply that for person A, who presents four mysided and two othersided arguments, we get a myside bias indicator of "2". The same myside bias would be achieved by a person B, who recalls ten mysided and eight othersided arguments. I argue that these two persons, however, do *not* show the same degree of mysided thinking. In the present dissertation the *ratio* of mysided and othersided arguments is proposed to be a more sensible measure of myside bias.

Myside bias was also assessed by means of rating Ss' essays stating their personal opinion (see Chapter 3 for the rating scheme). Level 3 in the reflective judgement scoring represents opinion statements that clearly take an own position. They also provide a sufficient rationale by presenting arguments supporting the position taken. However, these essays fail to provide possible counterpositions and do not integrate counterarguments and rebuttals of these counterarguments. The mean reflective judgement score achieved by Ss of study 1, for example, was M = 2.97, which indicates that these Ss showed a myside bias in their essays, that is, they failed to integrate possible counterarguments into their essays.

However, we cannot infer from the Ss' essays about their personal opinion (which they were asked to write down in both studies) whether they were not *able* to integrate counterpositions and refutations to counterarguments or whether they just did not do this as I did not ask for it, in this research. Therefore, a relatively new paradigm was used in study 2 to measure people's ability to take counterpositions into account and to construct rebuttals of these counterarguments: Ss of study 2 were asked to generate three reasons why other people might disagree with their personal opinion and to discuss these counterarguments for the purpose of refuting their own opinion. Research showed that this instruction for itself reduces the myside bias in argumentation – which might be an indicator that people do not refer to counterarguments as long as they are not explicitly instructed to do so (Cappella et al., 2002). A coding scheme was used in this research to assess opinion quality by means of this task and, in general, counterargument generation and rebuttal construction was shown to be a useful method to assess opinion quality. Further research is needed to validate both this paradigm and the coding scheme applied.

The use of the discussed measures for myside bias also exemplifies the conceptualization of good informal reasoning and critical thinking that was applied in the present dissertation: Good informal reasoning using critical thinking is defined as *unbiased reasoning* resulting in a deliberate and reflective judgement about a controversial issue in the present research. A similar conception was introduced recently by West et al. (in press) who propose to measure critical thinking by means of assessing biases in thinking and reasoning. This perspective integrates knowledge from cognitive psychology examining human reasoning into a broader view on critical thinking. In their experiment, lack of biases in reasoning tasks was associated with a more general ability to critically think measured by traditional methods (e.g., the Watson-Glaser Critical Thinking Assessment, Watson & Glaser, 1980).

West et al. (in press), however, used a standard paradigm to assess formal reasoning, namely the syllogistic reasoning task which solution is mainly based on logical reasoning. Formal logic, however, is insufficient for the study of arguments naturally made in discourse (cf. Shaw, 1996). Especially, ill-structuredness of arguments and lack of a “right” solution of informal reasoning tasks such as judging a controversial science topic like nanotechnology was a matter of particular importance for this research. For the purpose of this research, methods to assess individual differences in biased thinking had to be developed that are not based on rather formal logical reasoning tasks but are adequate to assess *informal* reasoning, too. In study 1, I introduced independence of post-visit attitudes from prior attitudes as a measure of *confirmation bias*. Lack of dependency - i.e., lack of a confirmation bias in attitude formation - was proposed to be an indicator of critical thinking. In study 2, degree of *myside bias* was further introduced as a measure of critical thinking and reflective judgement – as explained above. Measuring individual tendencies for biased thinking and biased judgement seems to be a promising way to assess critical thinking and reflective judgement in informal reasoning, too. Further research is still needed to relate biased thinking with more traditional critical thinking assessment methods and general thinking dispositions to validate assessment of quality of informal reasoning by means of degree of biased thinking.

5.3 Theoretical Implications

As pointed out in the introduction section of this dissertation, the ability to think critically about socio-scientific issues and to judge current science topics reflectively is one the desired outcomes of modern science education. The ability to take position was also part of several conceptualizations related to science communication, for example, it is a major part of public understanding of science (however, the emphasis here would be on formation of positive attitudes and general interest in science) and it is also regarded as an essential part of scientific literacy (for an overview of these and other related concepts of science education, see Burns, O'Connor, & Stocklmayer, 2003).

Modern science museums are regarded as a major information source for current science issues today in the context of informal science learning. However, former research on learning science at museums focused strongly on both content and processes of science by means of presenting facts and figures but also exemplifying the process of knowledge construction to raise understanding of science and research (Bradburne, 1998). The outcome of "opinion formation", which was central to the present research, was addressed only partly by research on how people's attitudes towards science relate to their content knowledge and how people's attitudes might be positively influenced by dissemination of factual knowledge.

In recent years, several museum exhibitions have been developed that address contemporary and controversially discussed science topics (e.g., A Question of Truth, The Ontario Science Center, Pedretti, 2004; Mine Games, Vancouver's Science World, Wake & Bradburne, 1994). These exhibitions present science issues contextually bound with all their social, ethical, political, and economic dimensions. However, judgement of the efficiency of such science exhibitions requires a thorough understanding of the museum visitors' cognitive engagement with a controversial science issue. Identifying crucial factors that support people in forming well-founded and sophisticated opinions about contemporary science topics in the context of a science museum exhibition was therefore the major aim of this dissertation. Study 1 of this dissertation showed, however, that factual knowledge was not directly related to quality of opinion and did not suffice for the formation of well-founded opinions. To identify factors that are crucial for deliberate opinion formation, literature from attitude formation, informal reasoning, science education, and science communication was integrated. The intuitive assumption that the opportunity to express an own opinion – to be actively involved – would foster critical thinking about presented arguments and relevant factual information, was not supported, however. On contrary, expressing an overall opinion only seems to trigger superficial cognitive processes that are based mainly on the application of heuristics and biases (e.g., confirmation bias as shown in study 1). Even though all study participants had the opportunity to elaborate on the presented expert statements in the exhibition, this was not sufficient. Only active elaboration on expert statements and increased salience of the arguments was effective in supporting reflective judgement.

The analytical framework presented in Chapter 1 was helpful with regard to the identification of further crucial factors that foster deliberate opinion formation. Discussion-based media installations can effectively support opinion exchange between visitors thereby addressing several mechanisms of collaborative learning in science exhibitions, for example, socio-cognitive conflict (if disagreement is encountered) and argumentation (as part of the explication of a personal opinion and refutation of this opinion against counterarguments from other people). Research from social psychology provides knowledge about the processes by which people change (and potentially optimize) their attitudes and opinions by means of confrontation with opposing views and argumentation (see Chapter 2). The focus in this research lay on the impact of social influence and persuasive communication on individual judgement and opinion change. The present dissertation examined further effects of disagreement on quality of the individual opinion. In doing so, this dissertation contributes to our understanding of social influence and the impact of disagreement between lay people with regard to individual opinion formation processes. From this research, hints for the design of effective exhibits can be derived that foster critical thinking and reflective judgement.

5.4 Implications for the Design of Discussion-Based Media Installations

The results of the first study indicate that the expression of one's personal opinion without salience of controversial arguments leads to top-down processes of opinion formation - which in turn result in suboptimal opinions and biased attitudes. This implies that it is important for the design of discussion-based installations to provide explicit support for deliberate opinion formation by providing opportunities to deal with relevant pro and con arguments. Salience of arguments and prompts for critical evaluation of relevant arguments were shown to be necessary for the formation of well-founded, sophisticated opinions that are independent of prior beliefs. Discussion-based installations that encourage elaboration on controversial arguments from a broad range of perspectives and scaffold integration of ambivalent information into an overall judgement are promising as support for the formation of opinions that are independent from prior beliefs. It seems necessary that visitors are guided in careful examination and evaluation of arguments - as the first study showed that simple presentation of relevant information was not enough for deliberate opinion formation. In fact, Ss who did *not* interact with relevant arguments at the discussion terminal ended up forming opinions that were highly influenced by their prior attitudes - even though these were weak and not extreme in general. Prompts to evaluate arguments with regard to persuasiveness and personal agreement were shown to be effective as support for deliberate opinion formation.

The second study revealed that disagreement among visitors and feedback about others' opinion further enhances opinion formation and reflective judgement as it elicits careful consideration of counterpositions and counterarguments. Information about others' opinion should therefore be provided at discussion terminals. In this research, aggregated feedback about others' average position was provided. Encountering disagreement with other visitors was shown to be effective in stimulating integration of counterpositions and in reducing the myside bias in argumentation. Introducing feedback about a disagreeing *majority* in this research aimed at amplifying the potential of encountering disagreement: We assumed that the information that many other visitors disagree would elicit the motivation to think about the others' judgement and their rationale. Of course, faked feedback about a disagreeing majority is not desirable for the naturalistic setting of a science exhibition. I will therefore present some alternatives for the implementation of information about opposing views of other visitors: It is possible, for example, to implement an algorithm that selects *some* statements of other visitors, who disagree with an individuals personal judgement, based on the individual's overall judgement *pro* or *con* and that displays these statements together with the information that opposing views on the topic have been expressed at the discussion terminal, too. This approach would ensure that all museum visitors might benefit from encountering disagreement regardless of whether or not they expressed a rather deviant opinion compared to other visitors.

It is also imaginable that feedback about a disagreeing *minority* (i.e., that *some* of the other visitors disagree for certain reasons) would also be beneficial for deliberate opinion formation. A prerequisite in the latter case would be to elicit the motivation to elaborate on the minority position, which might be accomplished by means of a very salient visualisation of the opposing view of the minority (cf. the work of Buder & Bodemer, 2008, on awareness tools to enhance group discussions when the minority has necessary information to solve a problem). Two major factors that seem to have an impact on the influence power of minorities are source group identity (whether or not the minority is regarded as relevant references group at all) and attributional reasoning (whether or not the deviant judgement of the minority is attributed to external reality, namely the "truth" about an issue under discussion). Under certain conditions, thus, *minority* influence can trigger a careful consideration of the issue under discussion (Mackie, 1987; Moscovici, 1980, 1985).[5]

In general, based on the notion that people generally project their own judgement on similar others (as explained in chapter 2), it seems to be valuable to make the controversy among visitors aware *by any kind of visualisation,* even without a direct comparison of a visitors' position with a disagreeing minority or majority. Figure 6 shows an implementation of a discussion-based media installation, which is based on video recordings of visitors' personal visions about nanotechnology.

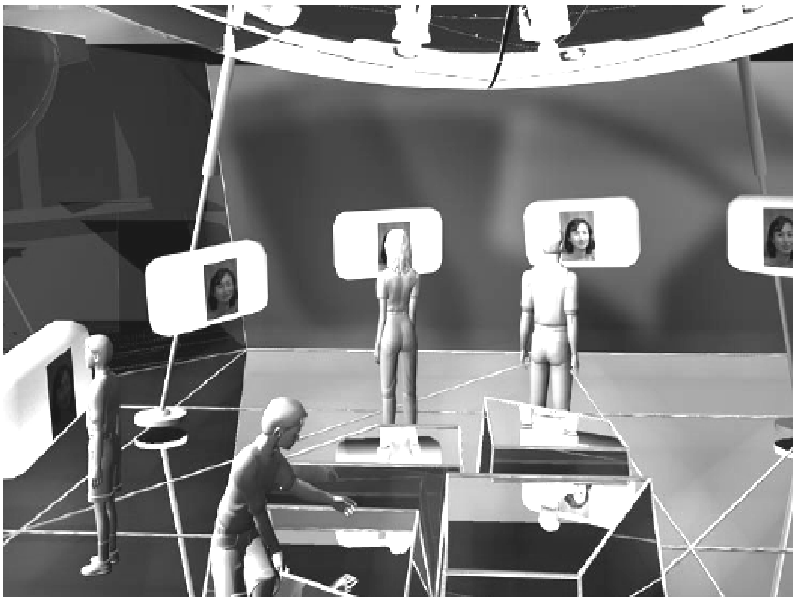

Figure 6. Discussion space that makes video recordings of visitors' personal visions about nanotechnology accessible to other visitors

[5] Research shows, however, that minority and majority source status induces different types of influence and outcomes (cf. Martin, Hewstone, & Martin, 2003; Wood, 2000).

Just the availability of various opinions make salient that there is a broad range of personal positions and different perspectives on the same issue (cf. the analyses of the impact of controversy on the ability to generate counterarguments to one's own position by Price, Capella, & Nir, 2002). Similarly, just *reading* through others' statements at the discussion terminal without explicit aggregated feedback can make the controversy among visitors aware and provides the opportunity to reflect on counterpositions.

To sum up these considerations on different implementations of information about others' judgement, further research is needed to test various forms of feedback and their differential effects on the individual judgmental process. The results of the second study, however, provide first insights into socio-cognitive factors in individual opinion formation, and they propose that information about others' position can be a valuable factor in supporting critical thinking and reflective judgement by means of discussion terminals.

5.5 Future Research

Theories of public opinion research (e.g., Noelle-Neumann, 1974, 1984) address the question of active participation and social inclusion in the context of contemporary and controversial issues. Several factors have been identified that determine whether a person will express a personal opinion in public, for example, the issue itself, the form of opinion expression, issue knowledge and personal involvement, perceptions of the majority opinion, level of education and other demographics, etc. (Kim, 1999; Salmon & Neuwirth, 1990; Salmon & Oshagan, 1990; Scheufele, 1999). Motivational issues concerning an individual's opinion expression were not addressed in this dissertation. However, prior experiences with participatory events (science cafés and debates for adults) held in science centres and museums (e.g., at the Dana Centre, London) show that "it is often challenging to actively engage people, as there are many barriers impairing dialogue and active participation" (Rodari & Merzagora, 2007, p. 3). I propose that discussion-based media installations can be successfully implemented to overcome the barriers for participation and engage citizens in the dialogue on social and ethical issues: They allow for a more or less anonymous participation and have a low degree of perceived publicity, and potentially unpleasant immediate feedback from other members of the public must not be feared. Future research in the field is needed to validate these assumptions.

In this dissertation, the museum visitors state their personal opinion only at the end of their museum visit. Differential effects can be assumed if they would have been asked to state their opinion prior to the museum visit. Then, issues of information selection and elaboration *during* the museum visit will become relevant, too. Asking for a second opinion expression at the end would also provide the possibility to examine changes in opinion due to informational input (e.g., Fazio, Eiser, & Shook, 2004; Jacoby et al., 2002). Similarly, time of provision of information about others' judgement would alter the effects probably: The statements made by other visitors might influence people's willingness to express their opinion but also shape their opinion formation processes (cf. Price et al., 2006). The opportunity to read through others' statements prior to own opinion expression will probably have different effects on individual opinion formation processes and evaluation of these statements will shape the development of an own opinion. Especially the perceived climate of opinion was shown to cause normative social influences in the sense that it might cause people to refraining from expressing an own opinion or by adapting it to the majority opinion (see Price et al., 2006). Future research might address these questions to broaden our understanding of the effects of discussion-based activities within the context of a science exhibition.

As has been mentioned in Chapter 4 already, two issues were not addressed in this dissertation, namely a) the question whether information about others' arguments for their opposing view would be necessary to cause informational social influence as shown by study 2 and b) whether mere exposure to voting results without further information on others' rationale would lead to similar effects on individual opinion formation. Research is somewhat controversial about the role of concrete arguments for others' opinion. Burnstein and Vinokur (1975) came to the conclusion that the information that other people disagree is sufficient to elicit implicit argumentation, that is, people think about the reasons why other's judgements are different from their own, which should have a beneficial effect on their opinion quality afterwards. Price et al. (2006), however, assign the provision of others' arguments a special role for the development of sophisticated opinions. This discussion is a relevant one for science exhibition curators as they might question that visitors are motivated and able to express well-founded rationales at discussion terminals. Future research might address this and examine the differential effects of "voting-only" media installations. Furthermore, the mentioned alternatives of providing information about disagreement among visitors in the chapter on implications on the design of discussion-based media installations (cf. above) need further examination. Research supposes differential effects of information about disagreement on individual choice contingent on source status (i.e., majority or minority status; e.g., Mackie, 1987; Martin, Hewstone, & Martin, 2003; Wood, 2000). Thus, generalizability of the results of study 2 on the effect of disagreement is limited for the time being.

In general, this dissertation has unlocked only some major potentials of discussion-based media installation for the communication of contemporary science topics and for support of museum visitors' opinion formation processes. The results of the two studies imply that discussion terminals might be a useful tool to bring a broader awareness of controversy in contemporary science topics, a deeper understanding of arguments given by a broad range of actors involved, and more deliberate opinion formation about those issues. Future research in this area might further contribute to a thorough understanding of learning about controversial science issues - which would be needed to successfully design science museum exhibitions on modern science topics like nanotechnology.

Summary

In the research framework proposed in this dissertation, science exhibitions are conceptualized as *dynamic information spaces for knowledge building* that are constituted by three major pathways of knowledge communication: museum-to-visitor, visitor-to-visitor, and visitor-to-museum knowledge communication. It is argued that advanced technologies have the potential to support all forms of visitor-to-visitor knowledge communication but additionally, they allow for new forms of knowledge communication among unacquainted visitors and beyond the actual museum visit. I analyze central learning mechanisms, namely socio-cognitive conflict, internalization of social processes, giving and receiving help, argumentation, co-construction of knowledge/group cognition, and active participation in knowledge building with regard to their relevance for learning in science exhibitions. Prototypical advanced media applications in science exhibitions that address these mechanisms are presented. This research framework both contributes to our understanding of collaborative learning in science exhibitions through visitor-to-visitor knowledge communication and provides valuable information for the purposeful design of advanced technologies for learning from science exhibitions.

These analytical considerations are then applied to examine the learning potential of discussion terminals for the communication of emergent technologies and contemporary science topics. For this purpose, a specific exhibition about nanotechnology - one of the most controversially discussed emergent technologies - is used as context. The specific challenge in communicating contemporary science topics is the fact that these topics are often discussed controversially, and science museums therefore face the challenge to adequately represent the ongoing public debate around such issues and to support their visitors in critical thinking and reflective judgement.

Discussion terminals are introduced as innovative kind of discussion-based media installations that both can foster *individual opinion formation processes* (study 1) and allow for *opinion exchange and debate among visitors* (study 2).

In a first study, the impact of expression of opinion and salience of arguments on participants' argument repertoire, opinion quality, and attitudes towards nanotechnology was tested in a 2x2 experimental design. Expression of opinion was revealed to have an impact on the argument repertoire but was not sufficient for formation of high-quality opinions. In contrary, asking for an overall judgement only seems to trigger top-down processes of opinion formation, that is, opinions and attitudes are formed that are highly dependent from prior attitudes and beliefs (confirmation bias, belief bias). Salience of arguments, however, was shown to be important for the formation of well-founded opinions and attitudes that are *independent* from prior attitudes.

However, the Ss still showed a myside bias in their essays on their personal opinion, that is, they were indeed enabled to generate a valid rationale to support their personal opinion but failed to integrate counterarguments and arguments to refute these counterarguments. This ability, however, is considered as major indicator for good informal reasoning and critical thinking. Thus, study 2 aims at specifying the potential of discussion-based installations to reduce the myside bias in judgement and thereby to further enhance critical thinking and reflective judgement. Based on the research framework presented, which explains the potential of visitor-to-visitor communication by collaborative learning mechanisms like socio-cognitive conflict or argumentation, encountering disagreement at the discussion terminal was proposed to be a major promoter of critical thinking and reflective judgement: Both awareness of what other people think and some understanding why they think so should foster deliberate opinion formation that takes also counterarguments into account.

The assumption that a major potential of discussion-based installations is confronting visitors with the opposing view of others was tested in a second study. 61 participants explored an exhibition about nanotechnology and stated their personal opinion at a discussion terminal. Following opinion expression, three levels of feedback about others' judgement were varied (agree, disagree, no information control). The results showed that participants who encountered disagreement by means of feedback about others' judgement after their opinion expression experienced this feedback negatively (they were disturbed, astonished and felt less comfortable than participants who did receive feedback about an agreeing majority or no feedback at all). These participants were also likely to change their opinion towards the majority opinion to reduce dissonance. Disagreement was shown to reduce the myside bias in the participants' argument repertoire, that is, Ss who encountered disagreement recalled as much othersided arguments as mysided arguments, whereas Ss of the control and the agreement condition provided more supportive arguments than counterarguments to their position. Furthermore, disagreement led to higher scores in reflective judgement: Ss of the disagreement condition were able to state their personal opinion, to give a valid rationale, and to integrate and elaborate on counterarguments in their statements about nanotechnology. Quality of counterargument generation and rebuttal construction was also higher for Ss of the disagreement condition indicating that these participants deliberately elaborated on the reasons why other people disagreed and were thereby enabled to construct valid rebuttals of others' counterarguments.

Both studies imply that a discussion terminal - when designed carefully - is a valuable facilitator of critical thinking and reflective judgement about contemporary science topics. Salience of arguments was shown to be necessary to support bottom-up formation of opinions independent from prior beliefs, and disagreement among visitors was shown to be efficient to reduce the myside bias in argumentation and to foster integration of possible counterarguments. Both a low confirmation bias and a low myside bias have been proposed as indicators of critical thinking and reflective judgement. I conclude from this that the discussion terminal was successful in enhancing critical thinking and reflective judgement.

Zusammenfassung

Längst haben Museen es sich zum Ziel gesetzt, nicht nur Faktenwissen zu vermitteln, sondern den Besucher gerade bei gesellschaftlich relevanten und kontrovers diskutierten Wissenschaftsthemen mit Perspektiven aus unterschiedlichen Wissenschaftsdisziplinen bekannt zu machen und ihn zu befähigen, sich selbst eine Meinung zum Thema zu bilden. In den letzten Jahren zeichnet sich ein Trend in der Museumslandschaft ab, dem Museumsbesucher an so genannten Meinungs- oder Dialogstationen die Möglichkeit zu geben, an aktuellen Debatten um wichtige Wissenschaftsthemen wie Gentechnik, Nanotechnologie oder Klimaänderung teilzunehmen, also wichtige Perspektiven und Argumente kennen zu lernen, die eigene Meinung mitzuteilen und Meinungen anderer Besucher kennen zu lernen.

In diesem Dissertationsprojekt wird die Frage adressiert, wie man Wissenserwerb und Meinungsbildung bei komplexen und kontroversen Themen unterstützen kann. Um das Potential innovativer Medienanwendungen in naturwissenschaftlichen und technischen Museen aufzudecken, werden zunächst prototypisch existierende Medien in Museen vorgestellt und im Hinblick auf ihre Funktion im Rahmen sozialer Interaktion und Kommunikation zwischen Besuchern diskutiert. Das spezifische Potential liegt meiner Meinung nach darin, dass Medien sowohl individuelle kognitive Prozesse unterstützen als auch neue und innovative Kommunikationsformen ermöglichen können. Aus bisherigen Forschungserkenntnissen wird abgeleitet, dass für die Kommunikation aktueller und zumeist kontrovers diskutierter Wissenschaftsthemen der *Diskussion und Debatte zwischen Besuchern* besondere Bedeutung zukommt: Am so genannten Diskussionsterminal hat der Besucher die Möglichkeit, ein eigenes Statement zum Thema "Nanotechnologie" einzugeben und Meinungen anderer Besucher zu lesen. Um die fundierte Meinungsbildung zu unterstützen, bietet das Meinungsterminal zum einen

kontroverse Expertenpositionen zur aktiven Auseinandersetzung vor der eigenen Meinungsäußerung und zum anderen Feedback über das Meinungsbild der anderen Besucher als soziale Vergleichsinformation nach dem Eingeben einer eigenen Meinung an. Inwieweit diese Funktionalitäten dazu beitragen können, Wissenserwerb und Meinungsbildung zu dem sehr kontrovers diskutierten und ambivalenten Thema Nanotechnologie zu fördern, wurde in zwei experimentellen Studien untersucht.

Die erste Studie untersuchte in einem 2x2 Design die Effekte der aktiven Meinungsäußerung selbst und die Rolle der Salienz der Argumente (in Form von Expertenstatements) im Hinblick auf Indikatoren der Meinungsqualität. Dabei stellte sich heraus, dass die aktive Positionierung ohne Salienz der Argumente zu einem *confirmation bias* führt: Die Bewertung von Nanotechnologie am Diskussionsterminal nach dem Ausstellungsbesuch hing stark von der Voreinstellung zu Nanotechnologie ab. Nur unter Voraussetzung der Salienz der Argumente gelang die Integration der relevanten Argumente pro und kontra Nanotechnologie in ein deliberatives Gesamturteil. Dies zeigte sich zum Beispiel in der Unabhängigkeit der Einstellung nach dem Museumsbesuch von der Voreinstellung, in einem breiteren und balanciertem Argument Repertoire und letztlich auch in einer höheren Meinungsqualität im abschließenden Essay, in dem die eigene Meinung ausführlich und mit Begründung dargelegt werden sollte.

Es zeigte sich jedoch auch, dass die Museumsbesucher mit Hilfe des Meinungsterminals zwar in der deliberativen Meinungsbildung unterstützt werden konnten, aber in der Darlegung ihrer Meinung und im Argument Repertoire noch einen starken *myside bias* zeigen, d.h. sie setzten sich nicht ausreichend mit möglichen Gegenpositionen auseinander und integrierten Gegenargumente nicht explizit in ihre persönliche Bewertung. Die aktive Auseinandersetzung mit den (Gegen-)Positionen anderer Besucher sollte den myside bias verringern und zu einer erhöhten Meinungsqualität führen.

Deshalb erhielten die Teilnehmer in der zweiten Untersuchung Informationen darüber, zu welchem Gesamturteil die bisherigen Besucher im Durchschnitt gekommen sind. Dabei wurde der Konfliktgrad zwischen der eigenen Position und der Meinung anderer Besucher experimentell variiert. Es resultierte ein 1x3 Design (ohne Feedback, agreement und disagreement). Das konflikthafte Feedback sollte die Auseinandersetzung mit Gegenargumenten anregen und letztlich den myside bias verringern. Die Ergebnisse dieser zweiten Studie zeigen zunächst, dass - wie Theorien des sozialen Einflusses annehmen - „social projection" eintritt, d.h. die Versuchspersonen nehmen an, dass andere Besucher zur selben Meinung gekommen sind wie sie selbst, und dass deshalb die Information, dass die bisherigen Besucher zu einer anderen Bewertung tendierten, als konflikthaft wahrgenommen wurde. Die Auflösung der resultierenden kognitiven Dissonanz erfolgte nicht auf soziale Weise (normativer Druck, Assimilation der eigenen Meinung), sondern es wurden die am Meinungsterminal verfügbar gemachten Gegenargumente in die eigene Meinung integriert. Dies führte zu einem geringerem myside bias im Argument Repertoire und einer höheren Meinungsqualität im Essay. Außerdem konnten in dieser experimentellen Bedingung mehr Gegenargumente zur eigen Meinung konstruiert und erfolgreich die eigene Meinung dagegen verteidigt werden.

Beide experimentellen Studien legen nahe, dass ein Diskussionsterminal in sinnvoller Weise kritisches Denken und reflektiertes Urteilen in Wissenschaftsmuseen unterstützen kann. Insbesondere die Salienz relevanter Pro und Kontra-Argumente erwies sich als ausschlaggebend für eine Bewertung, die unabhängig ist von Voreinstellungen. Die Möglichkeit, die Meinung anderer Besucher und dabei auch Gegenpositionen kennenzulernen, trägt in großem Maße dazu bei, dass auch

Gegenargumente in die eigene Bewertung einfließen und somit die Qualität der eigenen Meinung steigt.

Die Ergebnisse der vorliegenden Dissertation tragen zu einem besseren Verständnis der Konzepte “kritisches Denken” und “reflektiertes Urteilen” in informellen Settings wie Museumsausstellungen bei und ermöglichen damit erst die gezielte Förderung der notwendigen Fertigkeiten und Kompetenzen. Die beiden experimentellen Studien erlauben es, konkrete Gestaltungsprinzipien und -anforderungen für innovative Medienanwendungen für die Unterstützung kritischen Denkens und reflektierten Urteilens abzuleiten.

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Appendix

A. The Virtual Exhibition Nanodialogue

B. Activities at the Discussion Terminal: Study 1

C. Feedback about Others' Opinion: Study 2

D. Questionnaires: Study 1

E. Questionnaires: Study 2

F. Coding Schemes Study 1 and 2

A.

The Virtual Exhibition “Nanodialogue”

A.1 Screenshots of the Virtual Exhibition „Nanodialogue“

A.2 Content of the Exhibition „Nanodialogue“

Facts or Fantasy?

Text	Wie wird die Nanotechnologie unser Leben in den nächsten 20 Jahren verändern? > Mark Welland Die Summen, die in die Nanotechnologie investiert werden (in den USA ist dieser Betrag höher als das Budget der NASA) werden dazu führen, dass unser Leben sich beträchtlich verändern wird. Wir werden in vielen Bereichen gewaltige Auswirkungen spüren. > Doug Parr Das ist schwer zu sagen. Es ist schwierig 20 Jahre in die Zukunft zu blicken. Wir sollten alle Vorhersagen darüber, wie sehr Technologien unser Leben verändern werden, mit Skepsis betrachten, da solche Prognosen oft falsch sind.
Pasteur	*Die Rolle des unvorstellbar Kleinen ist unvorstellbar groß.*
Jeremiah (US Navy)	*Militärische Anwendungen der Nanotechnologie haben ein noch größeres Potential, das globale Gleichgewicht der Mächte in der Zukunft radikal zu verändern als das bei Atomwaffen der Fall ist.*
NSF	*Vielleicht liegt die größte Schwierigkeit bei der Vorhersage der Auswirkungen neuer Technologien in der Tatsache begründet, dass sobald die technische und kommerzielle Durchführbarkeit von Innovationen gezeigt wird, nachfolgende Entwicklungen gleichermaßen in den Händen der Anwender wie auch der Erfinder liegen.*
Feynman (Nobelpreis Physik)	*Einer meiner Freunde (Albert R. Hibbs) schlägt eine sehr interessante Möglichkeit für kleine Maschinen vor. Er sagt, obwohl es eine kühne Idee ist, wäre es eine interessante Vorstellung den Chirurgen zu schlucken. Man setzt den mechanischen Chirurgen in ein Blutgefäß und er wird direkt ins Herz transportiert und kann sich dort ‚umsehen'. Er findet heraus welche Herzklappe fehlerhaft ist und nimmt dann ein kleines Skalpell und entfernt sie. Andere kleine Maschinen könnten permanent im Körper platziert werden, um ein nicht richtig funktionierendes Organ zu unterstützen.*
Stoermer (Nobelpreis Physik)	*Die Nanotechnologie hat uns die Werkzeuge an die Hand gegeben, um mit der ultimativen Spielkiste der Natur zu spielen - mit Atomen und Molekülen. Daraus besteht alles … Die Möglichkeiten neue Dinge zu erschaffen, erscheinen endlos.*
Pergamit & Peterson (Journalisten)	*Die Menschheit wird sich als Folge der Nanotechnologie einer mächtigen, immer schnelleren sozialen Revolution gegenüber sehen. In der nahen Zukunft werden Teams von Wissenschaftlern erfolgreich die ersten Nanoroboter bauen, die sich selbst reproduzieren können. Innerhalb einiger weniger Jahre und 5 Milliarden Nanoroboter später werden fast alle gegenwärtigen Industrieprozesse überflüssig sein, ganz genauso wie unser bestehendes Arbeitskonzep*
Greygoo	In der Science Fiction ist die Verwendung von Nanotechnologien oft mit dramatischen Zukunftsvisionen verbunden: Zwei bekannte Science Fiction-Romane, Drexlers *Engines of Creation* (1986) und Crichtons *Beute* (2002), zeigen ein Szenario, in dem sich selbst vermehrende Nanoroboter aus der Obhut ihres Schöpfers entfliehen und für Menschen zur

	tödlichen Bedrohung werden. Tatsächlich existieren Nanoroboter nur in der Science Fiction und sich selbst vermehrende Nanomaschinen - sei es selbstständig oder mit Hilfe biologischer Systeme - sind bestenfalls Zukunftsmusik. Dennoch gibt es heute schon "intelligente" Nanopartikel, wie z.B. Nanokapseln, die in der Lage sind, Medikamente im menschlichen Körper genau dorthin zu transportieren, wo sie gebraucht werden.
Missbrauch	Mit Hilfe der Nanotechnologie können Geräte hergestellt werden, die so klein sind, dass sie schier unsichtbar und damit einfach zu verbergen sind. Solche Geräte könnten eines Tages am menschlichen Körper angebracht werden und Informationen über ihren Träger liefern, z.B. darüber, mit wem sich diese Person trifft, wie viel Geld sie bei sich hat und so weiter. Dies alles führt zu einer breit angelegten Debatte über den Datenschutz, insbesondere nach der Entwicklung der RFIDs (Radio Frequency Identification Devices), die einen "elektronischen Produktcode" übertragen und jedes einzelne weltweit hergestellte Produkt identifizieren können. Ihre Übertragungsreichweite reicht von ein paar Zentimetern bis hin zum zweistelligen Meterbereich. Ihre Größe beträgt derzeit weniger als einen Millimeter und könnte in Zukunft noch weiter reduziert werden. Diese Systeme bieten eine Reihe von Anwendungsmöglichkeiten, wie z.B. die Identifizierung von einzelnen Personen zu Überwachungszwecken und die Bereitstellung von sicheren Zahlungs- oder Zugangsmöglichkeiten über einen unter die Haut implantierten Chip.
Überschreitungen	Da die Nanotechnologie auf Molekülebene arbeitet, ist die Angst, dass Wissenschaftler diese Technologie verwenden könnten, um DNA zu manipulieren, Hybride, Monster oder künstliche Lebewesen zu erschaffen, ein klassisches Science Fiction-Thema. Die Biotechnologie ist derzeit bereits in der Lage die genetische Information zu verändern, die Nanotechnologie könnte die menschlichen Manipulationsmöglichkeiten an der lebenden Materie auf ungeahnte Weise steigern. In der Tat wird in der traditionellen Biotechnologie das empirische Wissen seit langer Zeit verwendet, um Nahrungsmittel herzustellen (alkoholische Gärung, Brotherstellung, Käsefermentierung, etc.). Seit den 70er-Jahren wird die Gentechnik verwenden, um neue, modifizierte Organismen herzustellen: Einige von ihnen werden heute zur Insulinproduktion verwendet. Auch die Herstellung von Stammzellen oder das menschliche Klonen hängen mit der Steuerung der DNA-Konfiguration in der Zelle zusammen. Das Zusammenwirken von Technologie und Leben kann nützlich oder sogar lebenswichtig sein, wenn wir unseren gegenwärtigen Lebensstandard erhalten oder verbessern wollen. Gleichzeitig zieht die Verquickung dieser Elemente die Angst nach sich, dass die Wissenschaft eines Tages zu weit gehen könnte und aus Menschen Monster macht.
Rückseite	Was ist für Sie das Aufregendste und Unheimlichste an der Nanotechnologie? > Doug Parr Ich finde die Möglichkeiten toll, mit der Nanotechnologie saubere Energie zu erzeugen.

	Was ich unheimlich finde ... ist die Verquickung von Nanotechnologie und Biotechnologie, wenn - und es ist wirklich nur ein "wenn" - sie sich der biologischen Instrumente bedient, um sich selbst vermehrende Objekte herzustellen. Ich spreche hier von Cyborgs, nicht so sehr vom Grey Goo (= Grauer Schleim). Allerdings wird noch ein Jahrzehnt dauern bis man soweit ist, und vielleicht wird es auch nie passieren. > Mark Welland Ich finde die Tatsache aufregend, dass derart kleine, schöne Strukturen Auswirkungen auf etwas haben, das 1000 Millionen Mal größer ist und ein solch enormes Potential für neue Anwendungen bieten. Vor etwas bestimmten habe ich keine Angst. Ich bin eher besorgt, dass wir nicht alle Eventualitäten erforschen.
Interview	Wo stehen wir heute in der Nanotechnologie und was wird uns die Zukunft bringen? Wir haben zwei Menschen mit unterschiedlichem Hintergrund um ihre Meinung gebeten. (aus: BigPicture on Nanoscience herausgegeben vom Welcome Trust, Juni 2005) Dr Doug Parr ist wissenschaftlicher Chefberater von Greenpeace, einer der bekanntesten, nichtstaatlichen Umweltorganisationen. Professor Mark Welland ist Professor für Nanotechnologie und Direktor des Interdisciplinary Research Centre for Nanotechnology und des Nanoscience Centre an der Universität Cambridge.

Historischer Hintergrund

Seite 1	1857 Michael Faraday entdeckt, dass kolloidale Goldpartikel in Lösung besondere Farbeffekte zeigen. Eine Lösung, die üblicherweise transparent ist, erscheint unter bestimmten Lichtverhältnissen rot, grün, blau oder violett. 1905 Albert Einstein entwickelt eine quantitative Theorie über das Verhalten einer Kolloiddispersion. Er glaubt, dass sich Kolloide wie “große Atome” verhalten und erklärt ihre Bewegungen mit der Brown’schen Molekularbewegung.
Seite 2	1909 Wilhelm Ostwald bekommt als einer der Begründer der Kolloidchemie den Nobelpreis für Chemie. Er definiert Kolloide als dispergierte Systeme, die kleine Partikel mit einer Größe zwischen 1 und 100 Nanometer (nm) enthalten. Ostwald untersucht systematisch verschiedene Arten von Kolloidsystemen und entdeckt die Regeln der Farbdispersionen. 1953 James Watson und Francis Crick klären die Struktur der DNA (einer Nukleinsäure) auf, die den genetischen Bauplan zur biologischen Entwicklung der Lebewesen (und der meisten Viren) enthält. Zusammen mit Maurice Wilkins bekommen sie im Jahr 1962 den

	Nobelpreis für Physiologie/Medizin.
Seite 3	1958 Richard P. Feynman hält seine richtungsweisende Rede “There is a plenty of room at the bottom” (d.h. *Ganz unten ist eine Menge Platz*), in der er die Möglichkeit diskutiert, Materie auf atomarer und molekularer Ebene zu verändern. Damit öffnet er für die Wissenschaft und Technologie die Tür zur Nanowelt. Feynman bekommt 1965 den Nobelpreis für Physik. 1974 Norio Taniguchi prägt den Begriff ‘Nanotechnologie’ und bezieht sich auf die technische Herstellung mit der Präzision von einem Nanometer.
Seite 4	1981 G. Binning und H. Rohrer erfinden das Rastertunnelmikroskop, das 3-D-Bilder von leitenden Oberflächen auf atomarer Ebene ermöglicht. Das Mikroskop verwendet dabei einen Punkt, der 2nm von der Oberfläche entfernt liegt und misst die elektrische Dichte der Oberfläche. 1985 R. Smalley, R. Curl und H. Kroto entdecken Fulleren C60, ein Molekül, das aus 60 Kohlenstoffatomen besteht und die Form eines Fußballs besitzt.
Seite 5	1991 S. Iijima entdeckt ein Verfahren zur Herstellung von Kohlenstoff-Nanoröhren. Dazu werden Graphitschichten zur Röhrenform aufgerollt. 1997 Herstellung des ersten “Nanotransistors”, einem Metalloxid-Halbleitertransistor mit einer Breite von 60 mm.
Seite 6	2000 ⇒ 2005 Nanotechnologien finden in vielen Bereichen Anwendung und führen zur Herstellung von… • molekulare Motoren mit Hilfe von DNA. • leistungsfähigeren Brennstoffzellen auf der Grundlage von Kohlenstoff-Nanoröhren. • schmutzabweisenden Materialien, die Kohlenstoff-Nanofasern enthalten. • Organischen Solarzellen, die Fullerene enthalten • Antifaltencremes, die ihren Wirkstoff mit Hilfe von Nanokapseln über eine längere Zeit abgegeben • selbstreinigendem, mit Nanokristallen beschichteten Glas • wiederaufladbaren Batterien, die Nanoröhren und Fullerene verwenden • flexibleren und doch robusteren Tennisschlägern, die mit Hilfe von Nanoröhren

	hergestellt werden …und vielem mehr ...

Into the nanoworld

Text	Ist Nanotechnologie nur eine Angst vor Veränderungen? > Doug Parr Es gibt keinen breit angelegten Widerstand gegen die Nanotechnologie. Nicht einmal Greenpeace steht ihr feindlich gegenüber: Ich hoffe, dass sich einige gute Dinge aus ihr ergeben werden. Es gibt jedoch Skepsis darüber, welcher Art diese sein werden. > Mark Welland Nein, es ist die Angst vor unbekannten Auswirkungen. Da physikalische Eigenschaften auf Ebene der Atome und Moleküle zu ungeplanten Eigenschaften und Konsequenzen führen können.
Colvin (CBEN)	*Wir haben überrascht festgestellt, dass in einem Bereich, der jedes Jahr mehr als 12.000 Veröffentlichungen hervorbringt, bisher keine Forschungsarbeiten zur Entwicklung von Modellen der Risikoanalyse bei Nanomaterialien und keine Toxizitätsstudien über synthetisches Nanomaterial existieren*
Mooney (ETC)	*Während Wissenschaftler in Südafrika Nanoteilchen behandeln als würden sie mit dem AIDS-Virus umgehen, tragen andere Forscher - darunter auch einige in Europa - als einzigen Schutz eine Atemmaske, wie sie viele Japaner auch in der U-Bahn tragen. Das ist als würde man ein Volleyballnetz verwenden, damit die Stechmücken nicht ins Zimmer kommen.*
Greenpeace	*Eine Möglichkeit ist, dass sich Proteine im Blut an die Oberfläche von Nanopartikeln anheften und damit ihre Form und Funktion verändern und ungewollte Folgen verursachen, wie z.B. die Bildung von Blutgerinnseln. Eine zweite Möglichkeit bezieht sich auf die Fähigkeit der Nanopartikel die menschliche Immunabwehr unbemerkt zu passieren, eine Eigenschaft, die für die Verabreichung von Medikamenten zwar wünschenswert, gleichzeitig aber auch besorgniserregend ist, weil sich potenziell gefährliche Substanzen an gutartiges Nanomaterial anlagern und auf ähnliche Weise im Körper verbleiben könnten.*
Donaldson (Uni	*Wir sind Nanopartikeln in der Umwelt bereits ausgesetzt - über die Luftverschmutzung der*

Edinburgh)	*Städte. Es ist wahrscheinlich, dass die von der Nanotechnologie-Industrie hergestellten Teilchen ähnliche Wirkung haben.*
Gsponer (Independent Scientific Research Institute)	*Die wahrscheinlichste und kurzfristigste Anwendung der Nanotechnologie wird im Bereich des Militärs liegen.*
Gee & Greenberg (Journalisten)	*In Abwesenheit von Beweisen, die belegen, dass es unbedenklich ist, sich den krebserregenden Stoffen heute auszusetzen, ist es klüger das Vorsorgeprinzip anzuwenden; also anzunehmen, dass es nicht unbedenklich ist, insbesondere, wenn die Krankheiten (oder die ökologischen Auswirkungen), die durch häufigen Kontakt hervorgerufen werden, keine bekannten Grenzwerte aufweisen, unterhalb derer es keine Auswirkungen gibt.*
Definition	Der Begriff Nanotechnologie bezeichnet die Herstellung, Veränderung und Charakterisierung von Teilchen, deren Abmessungen wenigstens 10 Millionen Mal kleiner als 1 Meter sind - oder anders gesagt: kleiner als 100 Nanometer.
Aufbruch	Was ist ein Nanometer? Nano (vom griechischen Wort für 'Zwerg') ist die Vorsilbe für Einheiten von 10^{-9}. Somit ist ein Nanometer ein Milliardstel eines Meters. Was macht Nanopartikel so einzigartig? Nanopartikel folgen nicht den Gesetzen der klassischen Physik, sondern denen der Quantenmechanik. Dies bedeutet, dass Nanopartikel optische, magnetische und elektrische Eigenschaften haben, die sich von denen größerer Teilchen unterscheiden. Können Sie sich vorstellen, dass eine Katze gleichzeitig lebendig und tot ist, so wie es das berühmte Gedankenexperiment mit Schrödingers Katze nahe legt? Entsprechend der klassischen Physik und Ihren Alltagserfahrungen ist das absurd - aber wenn Sie ein Bewohner der Nanowelt wären, wäre es für Sie völlig normal! Quantensysteme können sich gleichzeitig in überlagerten Zuständen befinden, die vom klassischen Standpunkt her nicht miteinander vereinbar sind (wie z.B. "lebendig" und "tot"). Wenn wir jedoch ein Nanoteilchen vermessen, muss es einen Zustand "wählen", und zwar einen einzigen aus allen möglichen Zuständen.

	Von welchen Zuständen sprechen wir? Natürlich ist das Konzept von lebendigen und toten Nanopartikeln lediglich philosophischer Natur. Die echten Zustände, die Quantensysteme annehmen können, sind beispielsweise Spannungs-, Ladungs-, Energie- und Drehzustände. Und damit kann man in der Quantenwelt einen Stromkreislauf konstruieren, bei dem der elektrische Strom gleichzeitig in gegensätzliche Richtungen fließt!! Auf Nanoebene nimmt das Verhältnis von Oberfläche zu Volumen zu (bei einem Teilchen von 30 nm befinden sich 5 % seiner Atome auf der Oberfläche, bei einem Teilchen von 3 nm, 50%). Da die Atome auf der Oberfläche reaktionsfreudiger als die im Zentrum sind, haben Nanopartikel eine größere Reaktionsfähigkeit als andere Substanzen. Diesen Umstand kann man sich zunutze machen - zum Beispiel bei Verbrennungsprozessen oder der Verbesserung von medizinischen oder kosmetischen Produkten. Die Besonderheit des Nanokosmos besteht auch in der Dominanz der Brownschen Molekularbewegung - der zufälligen Bewegung mikroskopisch kleiner Teilchen in Flüssigkeiten. Dieses physikalische Phänomen wurde zum ersten Mal 1827 von Robert Brown untersucht, der eine "schnelle oszillierende Bewegung" von in Wasser suspendierten Pollenkörnern unter dem Mikroskop beobachtete. 1905 folgerte Albert Einstein unter der Annahme, dass die kinetische Gastheorie auch auf Flüssigkeiten zutrifft, dass sich die Wassermoleküle zufällig bewegten. Als Resultat mussten sich die Pollenkörner unter dem zufälligen Beschuss von Molekülen der Flüssigkeit genau in der von Brown beschriebenen Weise bewegen. Wenn Sie sich also vorstellen wollen, wie es ist in einer Welt zu leben, in der die Trägheit zu vernachlässigen ist und die Viskosität dominiert, so denken sie an einen "Spaziergang im Orkan oder an ein Wettschwimmen in Melasse" ...
Rückseite	Wird die Nanotechnologie die Kluft zwischen den Reichen und Armen der Welt vergrößern? > Doug Parr Wenn das bestehende Modell der Technologieentwicklung weiterverfolgt wird, wird sich die Kluft vergrößern, da die Investitionen in die Nanotechnologie vornehmlich von und zum Wohle der reicheren Länder durchgeführt werden. Bestenfalls gibt es keinen Einfluss und keine Zunahme der Kluft.

	> Mark Welland *Die Gefahr besteht immer. Aber die Nanotechnologie ist einzigartig. Anders als andere Industrien, die Investitionsniveaus mit sich bringen, die für Entwicklungsländer unerreichbar sind, kann man mit ihr neue Materialien und Geräte sehr preiswert herstellen. Dies könnte zu einer Verringerung der Kluft zwischen den reichen und den armen Ländern führen.*

Who controls?

Text	Sind die Kontrollen ausreichend? > Mark Welland Hier ist es wichtig, ausgewogen und nicht überstürzt zu handeln. Einerseits müssen Kontrollen eingerichtet werden, wenn wir negative Auswirkungen kennen, denen wir Einhalt gebieten müssen, oder weil wir uns über die Folgen bestimmter Technologien unsicher sind. Sobald eine Unsicherheit oder eine negative Folge erkannt wird, müssen wir etwas unternehmen. Andererseits würden wir am Ende die gesamte Forschung und Entwicklung beschneiden, wenn wir alles im Interesse der Sicherheit kontrollierten. Wir müssen der Technologie auch erlauben sich zu entwickeln und nützlich zu sein. > Doug Parr Gesetzliche Rahmenbedingungen sind noch nicht angezeigt. Viel wichtiger ist doch die Frage ob ein rechtlicher Rahmen, der Wissenschaft und Technologie einschränkt, das bietet, was wir für die Gesellschaft wollen. Im Allgemeinen ist das ja nicht so, weshalb wir immer noch zentrale Elektrizitätswerke und keine preiswerten, Energie-effizienten Solarzellen haben.
Colvin (CBEN)	*Es ist schwierig Wissenschaftler oder Finanzmanager davon zu überzeugen, dass Studien über die Umweltauswirkungen gefördert werden sollten. Die unmittelbare Anerkennung für die Forschung, die Möglichkeiten aufzeigt wie unter Verwendung von Nanomaterialien z.B. Krankheiten geheilt werden können, ist größer als die Belohnung für die Entdeckung, dass ein Nanomaterial eine Krankheit hervorrufen kann.*
Plato	*Der Entdecker einer Kunst ist nicht notwendigerweise am besten geeignet um das Gute oder das Schlechte zu beurteilen, das denen entsteht, die diese Kunst ausüben.*
Mooney (ETC)	*Ich würde nicht sagen, dass das gefährlich ist. Wir wissen nicht, ob es gefährlich ist. Das*

	Problem ist, dass es auch niemand anders weiß.
Buerge (Risk Engineering Service)	*Noch niemals zuvor waren Risiko und Chancen einer neuen Technologie so eng miteinander verbunden wie dies in der Nanotechnologie der Fall ist. Es sind genau diese Eigenschaften, die die Nanopartikel so wertvoll machen und Bedenken über die Gefahren für die Menschen und die Umwelt gleichermaßen hervorrufen*
Lane (Rice Uni)	Jede Nation der Welt sieht in der Nanotechnologie eine Technologie der Zukunft, die die eigene Wettbewerbsposition in der Weltwirtschaft verbessern wird.
Mooney (ETC)	*So sehr gesundheitlichen und umwelttechnischen Bedenken auch Priorität eingeräumt werden muss, ist es dringend nötig, die Auswirkungen auf die (Welt)Wirtschaft zu erfassen und zu überwachen. Nanotechnologie bedeutet, dass sich die Rohstoffe, die wir derzeit als lebenswichtig ansehen, ändern werden und dass dies dramatische Auswirkungen auf die Entwicklungsländer haben wird, von denen viele vom Rohstoffexport abhängen.*
Heckl (DM)	*Die Öffentlichkeit weiß noch wenig über den Nanobereich. Daher ist es noch vordringlicher, dass wir (als Wissenschaftler) an die Öffentlichkeit treten, um einen Dialog auf der Grundlage von Fakten anzustrengen, bevor diffuse Ängste eine solche Debatte unmöglich machen.*
Zelle	Können Sie sich eine medizinische Therapie vorstellen, die in der Lage ist, kranke Zellen direkt zu behandeln und Medikamente gezielt in den nötigen Mengen freizusetzen? Mit Nanokapseln und Dendrimeren ist dies möglich! Nanokapseln sind Nanopartikel mit einem Hohlraum, in den Medikamente, Enzyme, Katalysatoren und sogar biologische Materialien gepackt werden können. Ihre Fähigkeit das Medikament direkt ans Ziel zu bringen und seine Freisetzung zu kontrollieren, machen sie besonders geeignet für die Verabreichung von Medikamenten und Kosmetika. Dendrimere sind Nanomoleküle mit Verzweigungen und Endgruppen, die um ein zentrales Kernmolekül herum angeordnet sind. Ihre verästelte, dreidimensionale Struktur bietet ein hohes Maß an Oberflächenfunktionalität und Vielseitigkeit. Der festgelegte Aufbau und die hohe Beladbarkeit machen sie zu ausgezeichneten Zelltransport- und Kontrastmitteln.
Fussball	Was hat ein Fußball mit einem Nylonfaden gemein? Ein Buckyball ist das wohl bekannteste Nanomolekül. Er hat eine käfigartige Struktur aus 60 Kohlenstoffatomen und besteht aus Fünf- und Sechsecken. Er gehört zur Familie der

	Fullerene, der dritten bekannten Form reinen molekularen Kohlenstoffs neben Diamant und Graphit. Buckyballs sind sehr stabile Moleküle und werden beispielsweise verwendet, um die Zugfestigkeit von Nylon zu verbessern. Aufgrund ihrer antioxidierenden Eigenschaften können Fullerene freie Radikale abfangen und finden in Gesundheitsprodukten Verwendung.
Tennis	Es ist widerstandsfähig aber flexibel, es leitet Elektrizität besser als Kupfer und Wärme besser als Diamant… was ist das? Kohlenstoff-Nanoröhren sind kleine Zylinder aus gerollten Lagen von Kohlenstoffatomen. Kohlenstoff-Nanoröhren können aus einer einzigen Hülle oder mehreren Hüllen bestehen, die ineinander passen wie russische Puppen. Aufgrund ihrer Flexibilität und mechanischen Stärke werden Kohlenstoff-Nanoröhren beispielsweise in Tennisschlägern verwendet, die dadurch steifer werden und sich weniger verbiegen, wenn der Ball auftrifft.
Quantenpunkte	Warum wechsle ich die Farbe, wenn ich wachse? Quantenpunkte sind Halbleiternanokristalle. Ladungsträger (z.B. Elektronen) in einem Quantenpunkt sind so weit eingeschränkt, dass ihre Energie nicht mehr kontinuierliche, sondern nur noch diskrete Werte annehmen kann. Quantenpunkte verhalten sich also ähnlich wie Atome. Die optischen und elektronischen Eigenschaften der Quantenpunkte hängen von ihrer Größe und Geometrie ab. Als Folge davon bieten Lösungen, die Quantenpunkte enthalten, unter ultraviolettem Licht eine große Bandbreite schimmernder Farbeffekte.
Kosmetik	Die Nanokapseln in diesem Anti-Aging-Mittel bringen die aktiven Substanzen gezielt in die richtige Hautschicht. Die Zahncreme enthält ein Biokomposit, das der natürlichen Zahnsubstanz ähnelt. Durch die Reaktion mit dem Speichel bildet sich daraus eine bioanaloge Schutzschicht am Zahnhals aus - die Zähne sind besser geschützt und weniger schmerzempfindlich.
Rückseite	Sollte die Öffentlichkeit an den Entscheidungen über die künftige Richtung der Nanotechnologie beteiligt sein? > Mark Welland Ja - wie bei allen Technologien. Die Frage ist: Wie stellen wir das an? Wir haben

	zusammen mit dem Guardian und Greenpeace ein Bürgerforum eingerichtet, das die Probleme an die Öffentlichkeit bringt. Aber das Forum ist begrenzt, es können nur etwa 20 Personen teilnehmen. > Doug Parr *Ja, wir sollten daran beteiligt sein. Wir sprechen doch über die Zukunft jedes einzelnen! Das Problem besteht darin, dass Entscheidungsträger die Öffentlichkeit in die Debatte nicht miteinbeziehen. Anders als in den meisten anderen Bereichen der Politik oder des gesellschaftlichen Lebens gibt es in der Wissenschaft keine Mechanismen um sicherzustellen, dass sich Entscheidungsträger gegenüber der Öffentlichkeit dafür rechtfertigen müssen wie oder was in der Forschung finanziert wird.*

Herstellung

Bottom Up	Wie werden diese Nanosysteme hergestellt? Ganz allgemein gibt es zwei unterschiedliche Ansätze: Bottom-Up-Verfahren: Hier werden aus kleinsten Baueinheiten größere Strukturen erschaffen. Beim Bottom-Up-Design werden die einzelnen Bauteile zuerst genau festgelegt. Diese Teile werden zu größeren Einheiten verbunden, die dann zusammen die gewünschte Struktur ergeben. Der gesamte Prozess ähnelt damit dem Bauen mit LEGO-Steinen.
Top Down	Top-Down-Verfahren: Bei diesem Verfahren werden Strukturen aus dem Ausgangsmaterial herausgearbeitet. Dies ist vergleichbar mit der Arbeitsweise eines Bildhauers, der eine Skulptur aus einem Marmorblock heraus meißelt. In der Industrie wird dieses Verfahren z.B. dazu verwendet um mit Hilfe der Elektronenstrahllithographie die Schaltkreise eines Nanochips zu erzeugen. Dabei "schreibt" ein Elektronenstrahl die erforderlichen Strukturen, dann wird das überschüssige Material weggeätzt.

Anwendung

Text	Sind Nanosysteme Teil unseres täglichen Lebens? Natürlich! In der Natur gibt es eine Vielzahl an Beispielen für ultrafeine Partikel, wie z.B. Gase, Vulkanasche oder Pollen. Alle Verbrennungsprozesse könnte man als

	nanotechnologisch relevant bezeichnen, da dabei Partikel in Nanometergröße entstehen. In letzter Zeit begann man damit die besonderen Eigenschaften von Nanopartikelen dafür einzusetzen, um bereits bekannte Produkte zu verbessern. Was ist das Ergebnis? Extrem leichte und sehr widerstandsfähige Materialien finden Einsatz z.B. in Tennisschlägern, Fahrrädern, selbstreinigendem Glas, das nicht beschlägt, aber auch in rost- und kratzfesten Oberflächen, die beim Auto- oder Schiffsbau Verwendung finden. Aber auch in der Kosmetik ist der Einsatz von Nanomaterialien weit verbreitet. Der Einsatz von Nanopartikeln in Kosmetikprodukten hat die Wirkung von Anti-Aging-Cremes verbessert und für brillantere Farben gesorgt. Im Bereich der Medizin verwendet man Nanotechnologie um spezielle Beschichtungen für Prothesen oder Implantate herzustellen. Man entwickelt auch Nanostrukturen, die Medikamente an die richtige Stelle im Körper bringen und gezielt dort freisetzen, oder künstliche Gelenke, die im Körper besser verträglich sind. Was hat also eine wiederaufladbare Batterie mit einem Tennisschläger, einem Lippenstift und einem Speicherchip gemeinsam? Nun, natürlich die Nanotechnologie!
Militär	Nano und das Militär In der näheren Zukunft werden wahrscheinlich auch im militärischen Bereich Produkte der Nanotechnologie zum Einsatz kommen: Das kann von Patronen bis hin zu Kampfanzügen reichen. Die Eigenschaften der Nanomaterialien können die Wirksamkeit der Waffen erhöhen, und für Schutz vor chemischen oder biologischen Kampfstoffen sorgen. Die meisten der Anwendungen sind streng geheim, aber es ist bekannt, dass bereits heute in 120mm-Panzergeschossen Nanopartkel enthalten sind: Die dadurch gesteigerte Reaktivität erhöht die Durchschlagkraft der Geschosse. Nanopartikel können aber auch die Uniform des Soldaten in eine aktive Barriere zum Schutz vor Projektilen, und vor chemischen und biologischen Angriffen verwandeln. Dazu könnte man in die Uniform Schläuche integrieren, in denen eine spezielle Flüssigkeit enthalten ist, die fest wird, sobald es zu einem Einschlag kommt. Damit wird diese Uniform nur dann zur kugelsicheren Weste, wenn es nötig ist. Aber Nanopartikel können auch als Sensoren dienen, chemische und biologische Giftstoffe aufspüren und Gegenmittel ins Blut des Soldaten abgeben.

Umwelt	Wird Nanotechnologie einen Einfluss auf die Umwelt haben? > Mark Welland *Alle Technologien haben einen Umwelteinfluss. Nanopartikel könnten sich als gesundheitsschädlich erweisen. Wir müssen deshalb verstehen lernen, wie sie sich in der Umwelt verhalten. Im Moment sind die erzeugten Mengen noch gering, aber sie könnten mit steigender industrieller Produktion stark anwachsen.* > Doug Parr *Selbstverständlich. Aber im Moment ist es noch schwer zu sagen, ob zum Guten oder zum Schlechten. Effektivere Solarzellen wären z.B. eine gute Sache.*
Nanodoktor	Wir alle haben unseren eigenen Nanodoktor! Neueste Forschungsergebnisse in der Medizin ermöglichten es Wissenschaftlern den ersten Prototypen eines "Nanodoktors" zu bauen. Das ist ein Nanoroboter, der sich im menschlichen Körper bewegen und zu kranken Organen wandern kann. Von außen gesteuert soll er den Patienten innen gezielt mit elektrischen Impulsen operieren. In ein paar Jahren soll die Nanobiotechnologie soweit sein, Nanomoleküle anzufertigen, die in den menschlichen Körper wandern und in ausgewählte kranke Zellen eindringen können, wodurch es möglich wäre, Tumore ohne Operation zu behandeln. Die Kosmetik entwickelt sich rasant weiter. Der Einsatz von Nanopartikeln sorgte für größere Farbbrillianz und für wirksamere Schönheitsprodukte. Lotionen und Cremes z.B. ziehen aufgrund der kleineren Inhaltsstoffe wesentlich tiefer in die Haut ein.
DM	Forschung im Deutschen Museum Dem deutschen Physiker Gerd Binnig und seinem Schweizer Kollegen Heinrich Rohrer gelang es 1982 erstmals, die dreidimensionale Struktur einer Materialprobe mit atomarer Auflösung sichtbar zu machen. Dafür erhielten die beiden Wissenschaftler 1986 den Nobelpreis. Das erste von ihnen gebaute Gerät können Sie in der Ausstellung Optik im Deutschen Museum in München bewundern. Dieses Mikroskop "sieht" die Probe nicht wie ein Lichtmikroskop, es rastert eine leitende Oberfläche mit einer feinen Spitze im Abstand von wenigen Atomdurchmessern ab. Dabei werden Tastspitze und Probe unter eine kleine elektrische Spannung gesetzt. Kommt die Spitze der Oberfläche nahe genug, so fließt der sogenannte Tunnelstrom, dessen Stärke

	vom Abstand der Spitze zur Oberfläche abhängt. Wird dieser Strom konstant gehalten, während die Spitze die Probe abtastet, erhält man ein Höhenprofil. Dieses wird vom Computer dargestellt. Die Anwendungsmöglichkeiten dieses Mikroskops sind sehr vielfältig, zum Beispiel in der Metallurgie, der Elektrochemie oder der Molekularbiologie. Doch das Rastertunnelmikroskop liefert nicht nur Bilder, sondern eröffnet auch die Möglichkeit des Arbeitens im atomaren Maßstab. 1989 gelang es zum ersten Mal, mit Hilfe des Tunnelmikroskops einzelne Atome gezielt auf einer Oberfläche anzuordnen. Im "Gläsernen Forscherlabor" im Deutschen Museum können Sie selbst einen Naturwissenschaftler bei seiner Arbeit am Rastertunnelmikroskop erleben und mit ihm in Dialog treten! Das hier gezeigte Gerät ist eine Eigenentwicklung aus dem Arbeitskreis von Prof. Heckl (LMU).
Fliese	Keramikfliesen mit Easy-to-clean-Beschichtung Die Oberfläche dieser Fliese ist mit einer Nanostruktur ausgestattet, die Wasser und organische Flüssigkeiten leicht abperlen lässt. Es entstehen keine Flecken, auch Schmutzpartikel werden leicht abgespült. Die Oberflächenstruktur ist den Lotusblüten oder den Blättern der Kapuzinerkresse nachgebildet. *Leihgeber: Nano-X (Deutschland)*
Rost	Schutz gegen Bildung einer Oxidschicht (Korrosionsschutzüberzüge) Einige dieser Metalloberflächen sind mit einer Nanobeschichtung überzogen, die beim Schmieden, Vergüten oder Heißformprozess aufgebracht wurde. Sie schützt sichtbar vor dem Verrosten und anderen Korrosionsprozessen und wird derzeit bei der Herstellung des neuen Volkswagens Passat eingesetzt. *Leihgeber: Nano-X (Deutschland)*
Fixbrat	Schwarz beschichtete Alufolie und Grillpfannen Bei schwarzen Grillpfannen und Alufolien ist die Aluminiumunterseite mit einem anorganischen Nanokomposit namens x-coat® Black 4001 beschichtet. Die schwarze Beschichtung verbessert die Wärmeübertragung und verringert gegenüber herkömmlicher Alufolie damit die Grillzeit um 30%. Außerdem wird das Grillgut knuspriger. *Leihgeber: Nano-X (Deutschland)*

Putzmittel	Reinigungs- und Pflegemittel Für nahezu alle Bereich im Haushalt stehen sogenannte Nanotechnologieprodukte bereit. So hüllen z.B. Nanopartikel im Imprägniermittel die einzelnen Textil- und Lederfasern ein und lassen sie deutlich widerstandsfähiger werden. Wasser und Schmutz können dadurch nicht an den Fasern haften und perlen einfach ab. Bodenreinigungsmittel sorgen in ähnlicher Weise für einen besseren Schutz der Oberflächen vor Verschmutzung.
Nahrung	Nahrungsmittelergänzung Mineralpartikel mit Silicium, Calcium und Magnesium in einer Größe von 1-3 Nanometer sollen als Wirkbestandteile dieses Narungsmittelergänzungsmittels u.a. Muskelverletzungen vorbeugen und Sportler leistungsfähiger machen. In einem Bericht des Magazins *Panorama* vom März 2006 wurde die Anwesenheit von Nanopartikeln in diesem Produkt allerdings angezweifelt.
Finger	Schutz vor Fingerabdrücken Diese Metallplatte ist zum Teil mit einem Nanokomposit beschichtet. Es schützt Metalloberflächen (Rostfreien Stahl, mattes Chrom, Nickel, Aluminium, usw.) vor Oxidationspuren (Anlaufen des Metalls). Auch Fingerabdrücke werden optisch weniger wahrgenommen. *Leihgeber: Nano-X (Deutschland)*
Elektro	Elektrokabel mit Flammschutz Natürliche Schichtsilikate in Nanometergröße sorgen nach einer chemischen Modifizierung im Kunststoffmantel dieser Elektrokabel für einen erhöhten Flammschutz. Im Brandfall bildet sich eine nicht brennbare Kruste, die zudem das Abtropfen des Kunststoffs und damit eine Ausweitung des Brandes verhindert. Das linke Foto zeigt einen Brandtest mit einem Elektrokabel mit Nanofil® (links) und einem Kabel mit normaler Plastikummantelung. Das neue Kabel ist weniger leicht entzündlich und entwickelt im Brandfall deutlich weniger Rauch. Außerdem tropft der geschmolzene Kunststoff nicht, sondern verkrustet an Ort und Stelle.
Helm	Helmvisier mit Anti-Beschlagbeschichtung Dieses Helmvisiers ist auf der Innenseite so beschichtet, dass es nicht mehr beschlägt,

	zum Beispiel durch den Atem des Helmträgers. Dieser "Anti-fog"-Effekt verbessert die Sicht und erhöht Tragekomfort und Sicherheit. *Leihgeber: Nano-X (Deutschland)*
LCD	Flüssigkristallanzeigen (LCD) Neue Flüssigkristallanzeigen (LCD) können Dank der Verwendung von Nanopartikeln in den Flüssigkristallen auch von der Seite noch gut betrachtet werden. Die Monomere reflektieren Licht nicht nur nach vorne, sondern auch zur Seite. Damit behält ein Fernsehbild auch dann seine Helligkeit und seine Brillanz, wenn man etwas schräg auf den LCD-Schirm blickt.
Chips	Gold-Nanoelektroden auf Glasoberfläche (links im Bild) Bei der Untersuchung von Wasserproben kann man mit diesen Elektroden zwischen infektiösen und nicht-infektiösen Bakterien unterscheiden. *Leihgeber: PCB (Spanien)* Nanochips (rechts im Bild) Um elektronische Geräte immer kleiner bauen zu können, wurde es notwendig die Größe der elektrischen Schaltkreise auf Nanometermaßstab zu reduzieren. Das führte zur Entwicklung von Nano-Transistoren und Nano-Speichern, die mit hoch auflösenden Lithographieverfahren produziert werden.
Textil	Schmutzabweisende Materialien Diesen Fasern wurden Nanopartikel beigefügt. Sie weisen Wasser und Öl ab und verschmutzen daher nicht so leicht. *Leihgeber: Nano-X (Deutschland)*
Solarzellen	Solarzellen In diesen photovoltaische Solarzellen wird Sonnenenergie durch organische Farbstoffe in elektrischen Strom umgewandelt. Das Prinzip ähnelt der Photosynthesereaktion von Pflanzen. *Leihgeber: ENEA (Italien)*
Wachs	Skiwachs Selbstorganisierende Schichten aus Polyelektrolyten und Fluoriensiden im Nanometermaßstab bilden die Basis dieses Skiwachses.

	Vorteile gegenüber eines herkömmlichen Wachses sind eine einfachere und schnellere Handhabung und eine längere Haltbarkeit des Belags.
RTM	Rastertunnerlmikroskop (RTM) Ein Rastertunnelmikroskop rastert eine leitende Oberfläche mit einer feinen Spitze im Abstand von wenigen Atomdurchmessern ab, wodurch sich atomare Strukturen sichtbar machen lassen. Dieses Gerät ist eine Eigenentwicklung aus dem Kreis von Prof. Heckl (LMU).

B.

Activities at the Discussion Terminal: Study 1

B.1 Condition 1 (Quiz, Control)

Willkommen beim Nano-Quiz! Kennst Du Dich aus im Nanokosmos? Hier kannst Du Dein Wissen prüfen. Atonomus hat 8 Aufgaben für Dich bereitgestellt!

Was ist ein Nanometer?

- [x] Ein Milliardstel Meter.
- [ ] Der Durchmesser eines Wasserstoffatoms.
- [x] Ein "Zwergenmaß".
- [x] 10^{-7} cm.

Wann ist die Nanotechnologie entstanden?

- [x] "Die Nanotechnologie" entstand erst in den letzten 30 Jahren.
- [x] Einige erste wissenschaftliche Erkenntnisse aus dem 19. Jahrhundert haben zur Entwicklung der Nanotechnologie beigetragen.
- [ ] Die Nanotechnologie wurde bereits im 2. Weltkrieg eingesetzt.
- [ ] Die Ursprünge gehen auf Plato zurück, während der industriellen Revolution wurden seine Entwicklungen wieder aufgegriffen.

Das Größenverhältnisse von einem Meter zu einem Nanometer entspricht in etwa der Größe eines Menschen zur

- [ ] ... zur Größe seiner Hand.
- [ ] ... zur Größe eines roten Blutkörperchens.
- [x] ... zur Größe seiner DNA.
- [ ] ... zur Größe seines Augapfels.

Welche der folgenden Wissenschaftsdiziplinen beschäftigen sich mit Nanotechnologie?

- [x] Elektrotechnik
- [x] Genetik
- [ ] Ökonomie
- [ ] Architektur

Welche Anwendungen sind bereits heute Realität?

- [x] gezielte Wirkstoffabgabe durch Nanokapseln
- [ ] Identifizierungs- und Zahlungsmöglichkeit über einen unter der Haut implantierten Chip
- [ ] sich selbst vermehrende Nanoroboter

Womit könnte man die Arbeitsweise des Rastertunnelmikroskops vergleichen?

- [x] Mit einem blinden Menschen, der sich mit dem Stock die Straße entlang tastet.
- [ ] Mit einem CD-Laufwerk, das eine CD abtastet.

- [x] Mit einem LP-Laufwerk, das eine Schallplatte abtastet.
- [ ] Mit der eines optischen Mikroskops.

Was hat ein Fußball mit der Nanotechnologie zu tun?

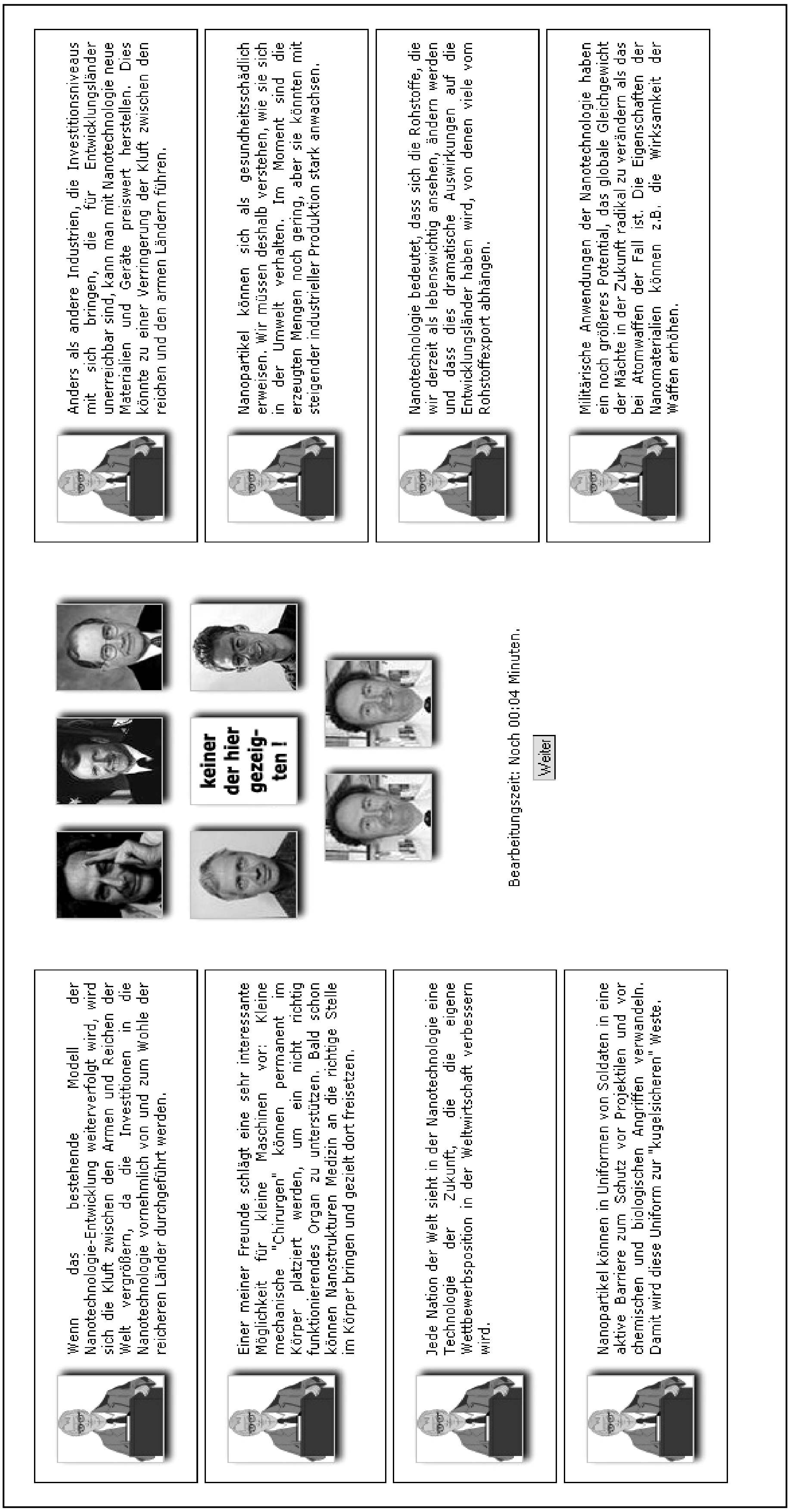
- [x] Bestimmte Nanopartikel haben die gleiche Form wie ein Fußball.
- [x] Ein Fußball besteht aus Nanopartikeln.
- [x] Die Bezeichnung "Buckeyball" in der englischen Sprache.
- [ ] Nanotechnologisch veränderte Fußbälle fliegen besser.

Die Leistungsfähigkeit von Computern steigt in den letzten Jahren, weil ...

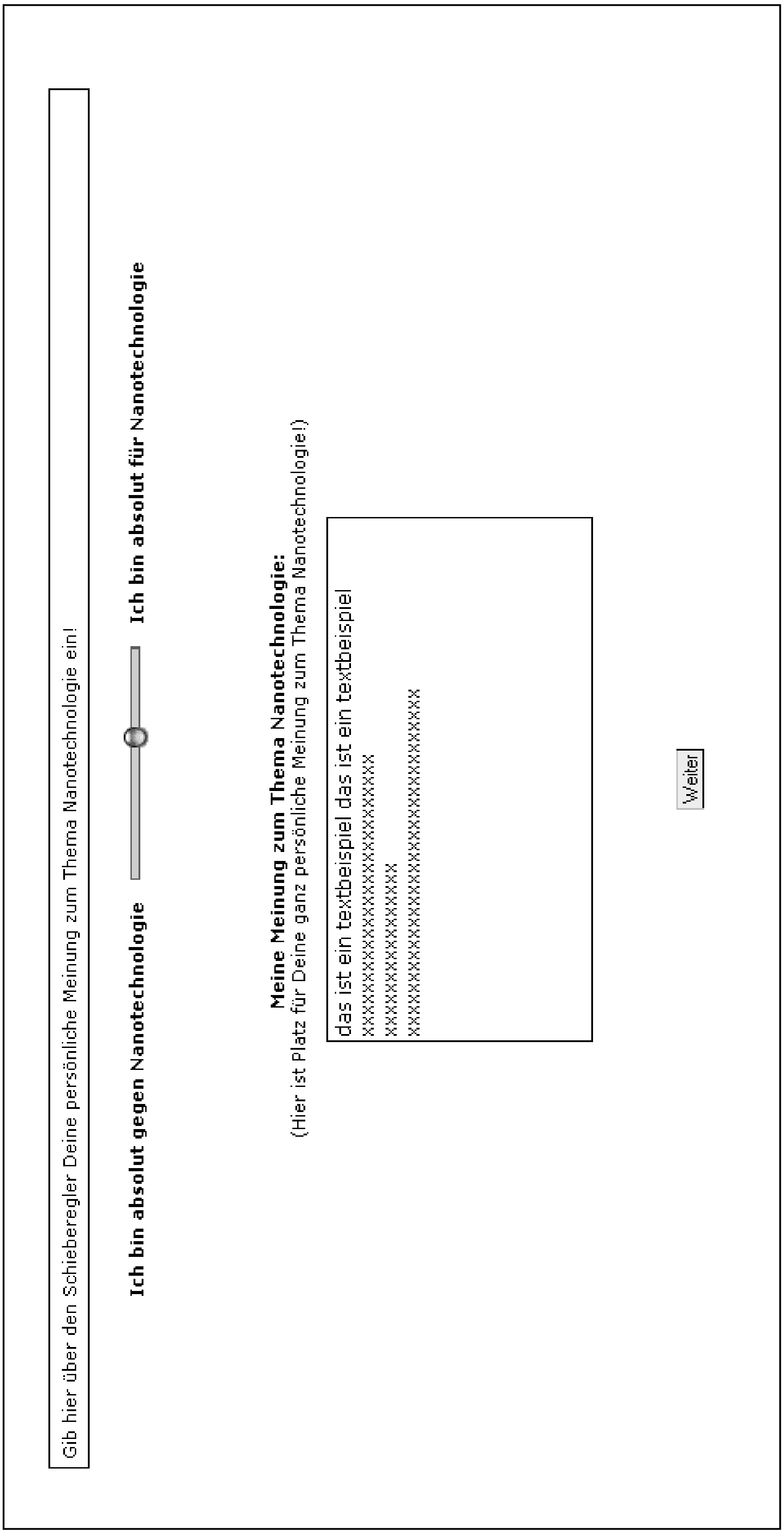
- [ ] ... in Nanochips der Strom in beide Richtungen fließen kann.
- [ ] ... Nanochips mehrere Datensets parallel speichern können.
- [x] ... immer kleinere Chips produziert werden können.
- [x] ... nanotechnologisch veränderte Chips eine größere Speicherkapazität haben.

Bravo. Du hast das Nano-Quiz geschafft!

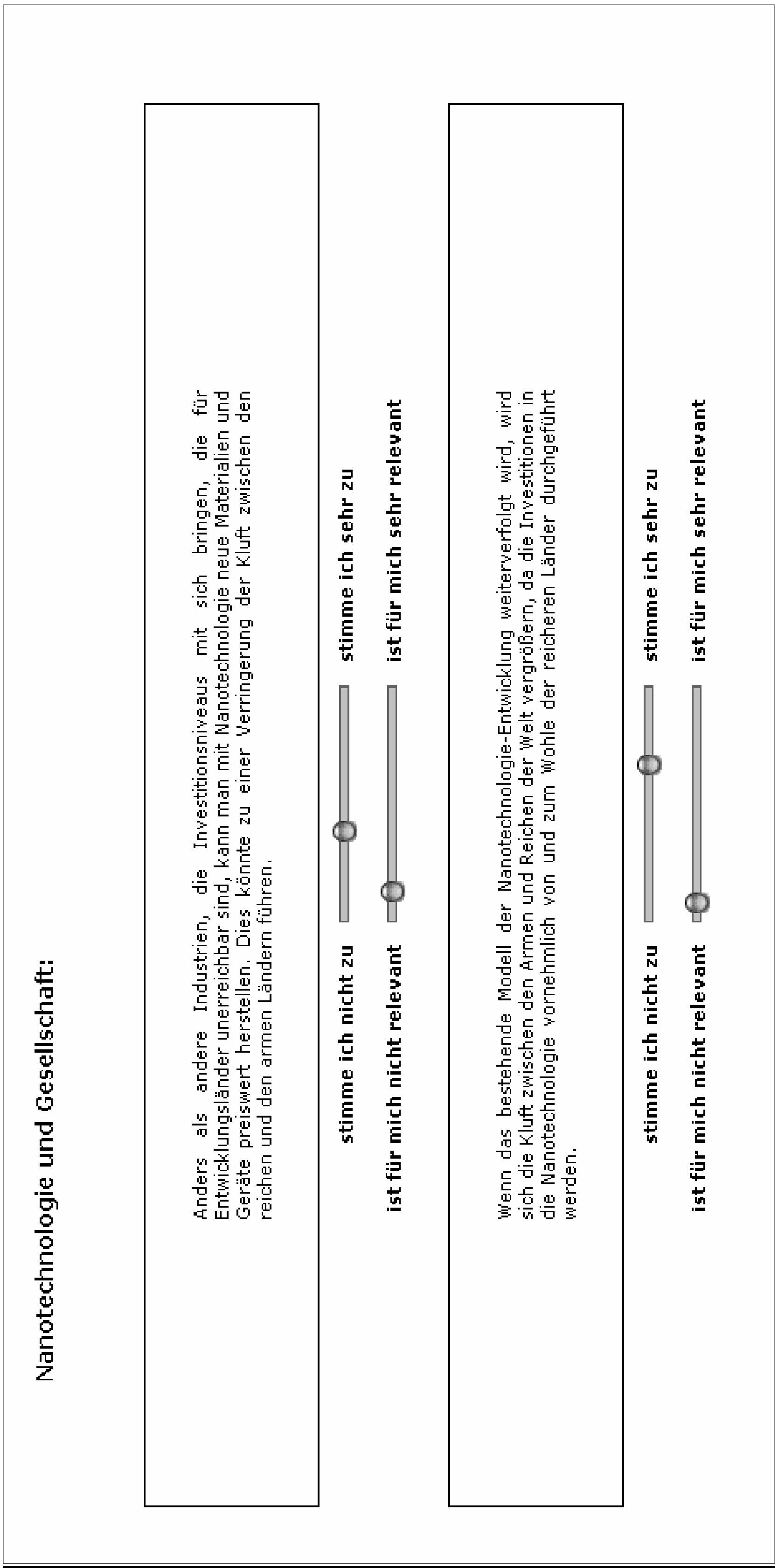
B.2 Condition 2 (Drag & Drop): Screenshot



B.3 Condition 3 (Overall Judgement): Screenshot



B.4 Condition 4 (Expert Statements): Screenshot and Expert Statements



Nanotechnologie und Gesellschaft

Pro: Anders als andere Industrien, die Investitionsniveaus mit sich bringen, die für Entwicklungsländer unerreichbar sind, kann man mit Nanotechnologie neue Materialien und Geräte preiswert herstellen. Dies könnte zu einer Verringerung der Kluft zwischen den reichen und den armen Ländern führen.

Kontra: Wenn das bestehende Modell der Nanotechnologie-Entwicklung weiterverfolgt wird, wird sich die Kluft zwischen den Armen und Reichen der Welt vergrößern, da die Investitionen in die Nanotechnologie vornehmlich von und zum Wohle der reicheren Länder durchgeführt werden.

Nanotechnologie und Gesundheit

Pro: Einer meiner Freunde schlägt eine sehr interessante Möglichkeit für kleine Maschinen vor: Kleine mechanische "Chirurgen" können permanent im Körper plaziert werden, um ein nicht richtig funktionierendes Organ zu unterstützen. Bald schon können Nanostrukturen Medizin an die richtige Stelle im Körper bringen und gezielt dort freisetzen.

Kontra: Nanopartikel können sich als gesundheitsschädlich erweisen. Wir müssen deshalb verstehen, wie sie sich in der Umwelt verhalten. Im Moment sind die erzeugten Mengen noch gering, aber sie könnten mit steigender industrieller Produktion stark anwachsen.

Nanotechnologie und Wirtschaft

Pro: Jede Nation der Welt sieht in der Nanotechnologie eine Technologie der Zukunft, die die eigene Wettbewerbsposition in der Weltwirtschaft verbessern wird.

Kontra: Nanotechnologie bedeutet, dass sich die Rohstoffe, die wir derzeit als lebenswichtig ansehen, ändern werden und dass dies dramatische Auswirkungen auf die Entwicklungsländer haben wird, von denen viele vom Rohstoffexport abhängen.

Nanotechnologie und Militär

Pro: Nanopartikel können in Uniformen von Soldaten in eine aktive Barriere zum Schutz vor Projektilen und vor chemischen und biologischen Angriffen verwandeln. Damit wird diese Uniform zur "kugelsicheren" Weste.

Kontra: Militärische Anwendungen der Nanotechnologie haben ein noch größeres Potential, das globale Gleichgewicht der Mächte in der Zukunft radikal zu verändern als das bei Atomwaffen der Fall ist. Die Eigenschaften der Nanomaterialien können z.B. die Wirksamkeit der Waffen erhöhen.

C.

Feedback about Others’ Opinion: Study 2

C.1 Algorithm for the (Faked) Feedback about Others' Overall Judgement in Study 2

Konsistenz (agreement)			Konflikt (disagreement)		
Rating:			Rating:		
(-100) - (-31)	(-31) - (+30)	(+31) - (+100)	(-100) - (-16)	(-15) - (+15)	(+16) - (+100)
Feedback:			Feedback:		
(-60)	(0)	(+60)	(+60)	Zufällig (+60) *oder* (-60)	(-60)

C.2 Faked Statements of Other Visitors Presented in Study 2 together with the Overall Feedback about Others' Opinion

Negative Overall Judgement

1. Ich bin erschrocken, dass so viele Möglichkeiten des Missbrauchs bestehen. Der Einsatz zu militärischen Zwecken macht mir Angst, es erscheint mir wahnsinnig, mit Nanotechnologie „bessere“ Tötungsmittel herzustellen. Und auch unter Gesichtspunkten des Datenschutzes ist Nanotechnologie in den falschen Händen ein großes Risiko.
2. Nanotechnologie - nein danke…Für besonders problematisch halte ich Klonen, "Roboter", sogenannte Monster, da sie den Menschen entmenschlichen und entwürdigen d.h. der Mensch ist nicht mehr das höchste Wesen, sondern eine lächerliche Gestalt, die nach Belieben veränderbar ist. Die Natur wird außer Kraft gesetzt und mittels molekularer Veränderung kann z.B. die DNA von Embryonen verändert werden, werden Behinderungen im Voraus festgestellt, kann man abtreiben, man kann also über das Leben von anderen entscheiden über natürliche Voraussetzungen hinweg.
3. Ich bin absolut gegen Nanotechnologie. Bedenklich finde ich vor allem den Einsatz in der Medizin. Da dies noch nicht ausreichend erfasst wurde mit all seinen Risiken. Was, wenn es zu unerwarteten Mutationen oder unerwarteten Reaktionen des menschlichen Körpers kommt, wenn Nanopartikel leichtsinnig eingesetzt werden, z.B. als „Operationsroboter“? Eingriffe durch "Nanochirurgen" in den menschlichen Körper finde ich gruselig…

Ambivalent Overall Judgement

1. Ich bin sehr zwiegespalten was die neuen Technologien betrifft. Sicher hat die Nanotechnologie viele Möglichkeiten, um unser Leben angenehmer zu machen, auch im Bereich der Medizin wird sie einiges leisten können, jedoch kann es möglich sein, dass sie am Ende die Krankheitsbilder bekämpfen muss, die sie selbst hervorgebracht hat. Man weiß nichts über die Auswirkungen dieser neuen Technologien auf den Menschen - und viel schlimmer auf unsere gesamte Umgebung, die wir so gerne in Mitleidenschaft ziehen, ohne uns wirklich darum zu kümmern.
2. Ich finde gut, dass Oberflächen vor Wasser und Dreck geschützt werden können und Menschenleben geschützt werden können z. b. Schutzwesten für Polizei und Bundeswehr. Aber um stärkere Waffen herzustellen, in den menschlichen

Organismus einzugreifen und die Identität jedes Menschen sofort abrufen zu können sollte Nanotechnologie nicht verwendet werden. Alles in Allem fällt es mir schwer, mich für oder gegen Nanotechnologie zu äußern, sie hat ja Vor- und Nachteile.

3. Ich bin in der Meinung, dass Nanotechnologie eine sehr nützliche Sache ist. Aber wie wird sie verwendet, es liegt an den Wissenschaftern. Es kann sehr schlecht verwendet werden (wie Waffen) oder kann sehr gut verwendet werden (wie Medizin). Aber auf jeden Fall kann die Technologie die Qualität unseres Lebens verbessern. Es ist Unsinn, an dieser Stelle ein abschließendes Urteil fällen zu wollen. Fragen Sie mich in 20 Jahren nochmal.

Positive Overall Judgement

1. Ich bin erstaunt, was man mit dieser Technologie so alles machen können wird. Am reizvollsten finde ich die Vorstellung, dass damit Technologien geschaffen werden, die einen großen Teil der Arbeit für den menschlichen Lebensunterhalt leisten könnten. Dann hätten die Menschen vielleicht mehr Zeit sich mit anderen Dingen zu beschäftigen.
2. Diese Technologie bietet Möglichkeiten, möglicherweise im Bereich Energiegewinnung Fortschritte zu erzielen. Entwicklungen in Richtung alternative Kraftstoffe wären eine echte Bereicherung für die Zukunft. Ich wäre begeistert, wenn wir durch Nanotechnologie zum Beispiel den Umweltschutz voranbringen könnten, indem wir den Schadstoffausstoß von Autos und Industrie minimieren oder ganz neue Wege finden (Brennstoffzellen im großen Stil einsetzen?).
3. Im Bereich der Medizin liegen gute Potentiale, man kann durch Nanopartikel neuartige Medikamente herstellen die auch den Krebs besiegen könnten. Prinzipiell sollte alles, was etwa der Vorbeugung bzw. einer besseren Behandlung von Krankheiten bei Mensch, Tier und Pflanze dient, weiter erforscht werden können und die entsprechende Unterstützung erfahren.

D.

Questionnaires: Study 1

D.1 Pretest

Prior Knowledge and Interest

1. Haben Sie schon von Nanotechnologie gehört?

□ ja □ nein

2. Was verbinden Sie damit? Was fällt Ihnen dazu ein?

____

____

____

3. Wieviel wissen Sie über das Thema Nanotechnologie?

überhaupt nichts sehr viel

□ □ □ □ □

4. Wie sehr sind Sie am Thema Nanotechnologie interessiert?

Überhaupt nicht sehr

□ □ □ □ □

5. Wie bedeutsam ist das Thema Nanotechnologie für Sie persönlich?

überhaupt nicht sehr

□ □ □ □ □

6. Wie schätzen Sie ihr Wissen in folgenden Bereichen ein?

Physik:

deutlich schlechter als der Durchschnitt deutlich besser als der Durchschnitt

□ □ □ □ □

Chemie:

deutlich schlechter als der Durchschnitt deutlich besser als der Durchschnitt

□ □ □ □ □

Biologie:

deutlich schlechter als der Durchschnitt deutlich besser als der Durchschnitt

□ □ □ □ □

Prior Attitudes

1. Wie beurteilen Sie insgesamt die Nanotechnologie?

sehr negativ sehr positiv

□ □ □ □ □

2. Wie sicher sind Sie sich in Ihrer momentanen Einschätzung von Nanotechnologie?

überhaupt nicht sicher sehr sicher

□ □ □ □ □

Need to Evaluate

[All items to be rated on a 5-point scale with „5“ = trifft genau zu]

1. *Ich bilde mir zu allem eine Meinung.*
2. *Ich vermeide es lieber, extreme Standpunkte zu beziehen.*

3. *Für mich ist es sehr wichtig, eindeutige Meinungen zu haben.*
4. *Ich will bei allem ganz genau wissen, was gut und was schlecht daran ist.*
5. *Bei komplexen Fragen bevorzuge ich es, einen neutralen Standpunkt einzunehmen.*
6. *Wenn mich etwas nicht betrifft, ergründe ich gewöhnlich nicht, ob es gut oder schlecht ist.*
7. *Es gefällt mir, neue Dinge sehr zu mögen oder abzulehnen.*
8. *Bei vielen Dingen habe ich keine Vorlieben.*
9. *Es stört mich, neutral zu bleiben.*
10. *Selbst wenn mich etwas persönlich nicht betrifft, habe ich gerne eine klare Meinung darüber.*
11. *Ich habe zu wesentlich mehr Dingen eine Meinung als die meisten anderen Leute.*
12. *Ich habe lieber eine eindeutige Meinung als keine.*
13. *Ich achte sehr darauf, ob etwas gut oder schlecht ist.*
14. *Ich bilde mir nur dann eine eindeutige Meinung, wenn ich es muss.*
15. *Ich bestimme bei neuen Dingen gerne, ob sie wirklich gut oder schlecht sind.*
16. *Gegenüber vielen wichtigen Themen bin ich ziemlich gleichgültig.*

<u>Need for Cognition</u>
[All items to be rated on a 5-point scale with „5“ = trifft genau zu]

1. *Ich würde komplexen Problemen einfachen vorziehen.*
2. *Ich mag die Verantwortung, die mit einer Situation einhergeht, die viel Denken erfordert.*
3. *Nachdenken gehört nicht zu den Dingen, die mir Freude bereiten.*
4. *Ich würde lieber etwas tun, das wenig Nachdenken erfordert, als etwas, das mit Sicherheit meine Denkfähigkeit herausfordert.*
5. *Ich versuche Situationen im Voraus zu erkennen und zu vermeiden, bei denen ich mit großer Wahrscheinlichkeit gründlich über etwas nachdenken muss.*
6. *Stundenlanges angestrengtes Nachdenken gibt mir das Gefühl von Befriedigung.*
7. *Ich denke nur so angestrengt nach wie unbedingt erforderlich.*
8. *Ich bevorzuge es, über die kleinen, alltäglich anfallenden Projekte nachzudenken statt über die langfristigen.*
9. *Ich mag Aufgaben, bei denen man nicht viel nachdenken muss, wenn man sie einmal gelernt hat.*
10. *Die Idee, mich auf meinen Verstand zu verlassen, um Karriere zu machen, reizt mich.*
11. *Ich liebe Aufgaben, bei denen ich mir für bestehende Probleme neue Lösungen ausdenken muss.*
12. *Neue Wege des Denkens zu erlernen, begeistert mich nicht allzu sehr.*
13. *Die Vorstellung von abstraktem Denken spricht mich an.*
14. *Ich würde einer Aufgabe den Vorzug geben, die intellektuell, schwierig und wichtig ist gegenüber einer Aufgabe, die eine gewisse Wichtigkeit hat, aber nicht viel Nachdenken erfordert.*
15. *Ich verspüre eher Erleichterung als Befriedigung, wenn ich eine Aufgabe fertiggestellt habe, die eine Menge an mentaler Anstrengung erforderte.*
16. *Für mich genügt es, dass die Aufgabe gemacht wird. Wie und warum es so und nicht anders funktioniert, kümmert mich nicht.*
17. *Ich bin eigentlich immer dabei, über irgendwelche Themen nachzudenken, auch wenn diese mich nicht persönlich betreffen.*
18. *Ich bevorzuge mein Leben angefüllt mit Puzzlestücken, die es zusammenzusetzen gilt.*

D.2 Opinion Questionnaire

<u>Ambivalence (Griffin-Index)</u>
Wenn ich an alle positiven Aspekte der Nanotechnologie denke, schätze ich diese Aspekte folgendermaßen ein:

überhaupt nicht positive				sehr positiv
☐	☐	☐	☐	☐

Wenn ich an alle negativen Aspekte der Nanotechnologie denke, schätze ich diese Aspekte folgendermaßen ein:

überhaupt nicht negativ				sehr negativ
☐	☐	☐	☐	☐

<u>Subjective Ambivalence</u>
Als ich meine Meinung zum Thema Nanotechnologie äußern sollte,…

…fühlte ich mich hin- und hergerissen.

trifft überhaupt nicht zu				trifft genau zu
☐	☐	☐	☐	☐

…hatte ich unvereinbare Gedanken.

trifft überhaupt nicht zu				trifft genau zu
☐	☐	☐	☐	☐

…hatte ich zwiespältige Gefühle.

trifft überhaupt nicht zu				trifft genau zu
☐	☐	☐	☐	☐

…waren meine Gefühle und Gedanken gleichermaßen positive wie negative.

trifft überhaupt nicht zu				trifft genau zu
☐	☐	☐	☐	☐

…wichen meine Gedanken stark voneinander ab.

trifft überhaupt nicht zu				trifft genau zu
☐	☐	☐	☐	☐

<u>Difficulty</u>
Mich zu entscheiden, ob ich Nanotechnologie gut oder schlecht finde, fiel mir…

sehr leicht				sehr schwer
☐	☐	☐	☐	☐

Mir eine Meinung zu bilden, ob ich Nanotechnologie gut oder schlecht finde, fiel mir…

sehr leicht				sehr schwer
☐	☐	☐	☐	☐

Certainty

In meiner Meinung über Nanotechnologie bin ich mir sehr sicher.

trifft überhaupt nicht zu				trifft genau zu
□	□	□	□	□

Die Wahrscheinlichkeit, dass ich meine Meinung über Nanotechnologie wieder ändere, ist sehr groß.

trifft überhaupt nicht zu				trifft genau zu
□	□	□	□	□

Jetzt, da ich mir eine Meinung über Nanotechnologie gebildet habe, bleibe ich dabei.

trifft überhaupt nicht zu				trifft genau zu
□	□	□	□	□

D.3 Posttest

Factual Knowledge

Wer prägte den Namen Nanotechnologie?

- □ Norio Taniguchi
- □ Wilhelm Ostwald
- □ James Watson und Francis Crick
- □ Richard P. Feynman
- □ Weiß ich nicht

Was heißt überhaupt „nano“?

- □ Nanos heißt auf griechisch Zwerg.
- □ Nanotechnologie ist der Oberbegriff für den Wissenschafts- und Technologiezweig, der sich der Erforschung, Bearbeitung und Veränderung von Strukturen beschäftigt, die kleiner als 100 Nanometer sind.
- □ Ein Nanometer ist ein Millionstel Millimeter (Abkürzung 1 nm). Diese Längeneinheit hat der Nanotechnologie ihren Namen gegeben.
- □ weiß ich nicht

Welche der folgenden Wissenschaftsdiziplinen beschäftigen sich mit Nanotechnologie?

- □ Medizin
- □ Astronomie
- □ Physik
- □ Chemie
- □ Psychologie

Nennen Sie bitte 5 Gegenstände, die mit Hilfe der Nanotechnologie hergestellt oder verbessert wurden!

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Drei Begriffe aus der Nanotechnologie. Was sagen sie Ihnen?

Quantenpunkt

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Nanokapseln

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Kohlenstoff-Röhrchen

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Das Größenverhältnisse von einem Meter zu einem Nanometer entspricht in etwa der Größe eines Menschen...

- □ …zur Größe eines seiner Blutkörperchen.
- □ …zur Größe seiner DNA.
- □ …zur Größe seines Augapfels.
- □ …zur Größe seiner Hand.
- □ weiß ich nicht

Was hat ein Fußball mit der Nanotechnologie zu tun?

- □ Die Bezeichnung "Buckeyball" in der englischen Sprache.
- □ Nanotechnologisch veränderte Fußbälle fliegen besser.
- □ Bestimmte Nanopartikel haben die gleiche Form wie ein Fußball.
- □ Ein Fußball besteht aus Nanopartikeln.
- □ weiß ich nicht

Womit könnte man die Arbeitsweise des Rastertunnelmikroskops vergleichen?

- □ Mit einem LP-Laufwerk, das eine Schallplatte abtastet.
- □ Mit der eines optischen Mikroskops.
- □ Mit einem CD-Laufwerk, das eine CD abtastet.
- □ Mit einem blinden Menschen, der sich mit dem Stock die Straße entlang tastet.
- □ weiß ich nicht

Warum sind Oberflächen aus Nanopartikeln so extrem kratzfest?

- □ Alle Kratzer und Beschädigungen werden sofort rekonstruiert, weil sich eine Schicht aus Nanopartikeln darüber legt.
- □ Weil die Oberfläche von Nanopartikeln im Vergleich zu ihrem Volumen so groß ist, haften sie besser aneinander und versiegeln so die Oberfläche.
- □ Die Schicht aus Nanopartikeln ist so glatt, dass jeder Versuch, sie zu beschädigen scheitert, da man sofort wieder abrutscht.
- □ Alle Kratzer und Beschädigungen auf nanotechnologisch optimierten Oberflächen sind so klein, dass sie das menschliche Auge nicht mehr wahrnehmen kann.
- □ weiß ich nicht

Warum sind Beschichtungen aus Nanopartikeln unsichtbar?

- □ Weil Nanopartikel zu klein sind, um Licht zu reflektieren.
- □ Nanopartikel schlucken das Licht und wandeln es in Wärmeenergie um.
- □ Nanopartikel erzeugen Infrarotlicht, das für das menschliche Auge unsichtbar ist.
- □ Nanopartikel brechen das Licht in kleinere Lichtwellen, die wir nicht mehr wahrnehmen.
- □ weiß ich nicht

Mit der Nanotechnologie ist es möglich, besonders gute Produkte herzustellen, zum Beispiel auch nanotechnologisch optimierte Sonnencreme. Was könnten Vorteile einer solchen Sonnencreme sein?

- □ Nanopartikel sind unsichtbar, weshalb kein störender weißer Film auf der Haut sichtbar ist.
- □ Nanopartikel ziehen tiefer in die Haut ein und sorgen so nach einmaligem Auftragen für dauerhaften Sonnenschutz
- □ Die Sonnencreme lässt sich sehr gleichmäßig verteilen, weil die Teilchen dort anhaften, wo sie aufgetragen wurden.
- □ Da Nanopartikel so klein sind, werden sie vom Körper nicht als Fremdkörper wahrgenommen und lösen so keine Allergien aus.

- ◻ weiß ich nicht

Wird ein Wassertropfen sich auf einer Oberfläche mit Lotos-Effekt zusammenkugeln oder ausbreiten?

- ◻ zusammenkugeln
- ◻ ausbreiten
- ◻ weiß ich nicht

Attitudes

Welcher Meinung sind Sie? Sind Sie für die Nutzung von Nanotechnologie…

…in der Medizin.

überhaupt nicht dafür				sehr dafür
◻	◻	◻	◻	◻

…in der Arbeitswelt bei Produktion und Dienstleistung.

überhaupt nicht dafür				sehr dafür
◻	◻	◻	◻	◻

…im Umweltbereich.

überhaupt nicht dafür				sehr dafür
◻	◻	◻	◻	◻

…für alltägliche Erleichterungen.

überhaupt nicht dafür				sehr dafür
◻	◻	◻	◻	◻

…für die nationale Sicherheit.

überhaupt nicht dafür				sehr dafür
◻	◻	◻	◻	◻

Was ist Ihre Meinung? Beurteilen Sie Nanotechnologie auf folgenden Dimensionen!

vertraut	◻	◻	◻	◻	◻	◻	◻	unheimlich
modern	◻	◻	◻	◻	◻	◻	◻	altmodisch
schädlich	◻	◻	◻	◻	◻	◻	◻	nützlich
menschlich	◻	◻	◻	◻	◻	◻	◻	unmenschlich
notwendig	◻	◻	◻	◻	◻	◻	◻	überflüssig
moralisch	◻	◻	◻	◻	◻	◻	◻	unmoralisch
kontrollierbar	◻	◻	◻	◻	◻	◻	◻	unkontrollierbar
natürlich	◻	◻	◻	◻	◻	◻	◻	unnatürlich
befreiend	◻	◻	◻	◻	◻	◻	◻	einschränkend
positiv	◻	◻	◻	◻	◻	◻	◻	negativ
risikoreich	◻	◻	◻	◻	◻	◻	◻	risikoarm
gefährlich	◻	◻	◻	◻	◻	◻	◻	sicher

Argument Repertoire

Sie haben nun viele Informationen zur nanotechnologie erkundet und auch einige Expertenstatements zu Chancen und Risiken kennengelernt.

Schreiben Sie nun bitte alle Argumente pro und kontra Nanotechnologie auf, die Sie z.B. in Form von Expertenstatements kennengelernt haben, unabhängig davon, ob Sie Ihnen zustimmen würden.

Kennzeichnen Sie jedes Argument mit einem "+" oder "-", je nachdem, ob Sie es als ein Pro oder ein Kontra Argument einschätzen.

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Opinion Quality

Sie haben sich vielleicht im Laufe des Ausstellungsbesuchs eine Meinung zum Thema Nanotechnologie gebildet. Finden Sie Nanotechnologie chancenreich oder risikoreich? Gefährlich oder vielversprechend?

Sie haben bereits einige Angaben dazu gemacht, nun möchte ich Sie bitten, in einem offenen Statement ihre Meinung ausführlich darzulegen. Bitte versuchen Sie, ihr Statement so gut wie möglich zu begründen, beziehen Sie sich dabei auf Informationen aus der Ausstellung. Ihr Statement sollte anderen Personen klar vermitteln, ob sie Nanotechnologie gut oder schlecht finden und warum.

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E.

Questionnaires: Study 2

E. 1 Pretest

Prior Knowledge and Interest
(see Questionnaires of Study 1)

Prior Attitudes
(see Questionnaires of Study 1)

Need for Cognition
(see Questionnaires of Study 1)

Social Comparison Orientation

Ich vergleiche häufig, wie es Menschen, die mir nahe stehen, im Vergleich zu anderen ergeht.

trifft überhaupt nicht zu ☐ ☐ ☐ ☐ ☐ trifft genau zu

Ich achte immer darauf, wie ich Dinge im Vergleich zu anderen hinbekomme.

trifft überhaupt nicht zu ☐ ☐ ☐ ☐ ☐ trifft genau zu

Wenn ich herausfinden möchte, wie gut mir etwas gelungen ist, vergleiche ich mich mit anderen.

trifft überhaupt nicht zu ☐ ☐ ☐ ☐ ☐ trifft genau zu

Ich vergleiche häufig meine soziale Situation mit der von anderen Personen (z.B. soziale Fertigkeiten, Beliebtheit etc).

trifft überhaupt nicht zu ☐ ☐ ☐ ☐ ☐ trifft genau zu

Ich bin nicht der Typ, der sich oft mit anderen vergleicht.

trifft überhaupt nicht zu ☐ ☐ ☐ ☐ ☐ trifft genau zu

Ich vergleiche mit oft mit anderen im Hinblick auf das, was ich im Leben erreicht habe.

trifft überhaupt nicht zu ☐ ☐ ☐ ☐ ☐ trifft genau zu

Ich tausche mit gerne mit anderen über Meinungen und Erfahrungen aus.

trifft überhaupt nicht zu ☐ ☐ ☐ ☐ ☐ trifft genau zu

Ich versuche oft herauszufinden, was andere denken, die ähnliche Probleme haben wie ich.

trifft überhaupt nicht zu ☐ ☐ ☐ ☐ ☐ trifft genau zu

Ich möchte immer gern wissen, wie sich andere in einer ähnlichen Situation verhalten würden.

trifft überhaupt nicht zu				trifft genau zu
□	□	□	□	□

Wenn ich mehr über etwas herausfinden möchte, versuche ich in Erfahrung zu bringen, was andere darüber denken.

trifft überhaupt nicht zu				trifft genau zu
□	□	□	□	□

Ich vergleiche meine eigenen Lebensumstände nie mit denen von anderen Menschen.

trifft überhaupt nicht zu				trifft genau zu
□	□	□	□	□

Self-Monitoring (Other-directedness)

In Gesellschaft anderer versuche ich nicht, Dinge zu machen oder zu sagen, nur um anderen zu gefallen.

trifft überhaupt nicht zu				trifft genau zu
□	□	□	□	□

Wenn ich unsicher bin, wie ich mich in einer Situation verhalten soll, schaue ich im Verhalten anderer nach Hinweisen.

trifft überhaupt nicht zu				trifft genau zu
□	□	□	□	□

Ich benötige selten den Rat meiner Freunde, um Filme, Bücher oder Musik auszuwählen.

trifft überhaupt nicht zu				trifft genau zu
□	□	□	□	□

Ich würde nicht meine Meinung ändern, um jemandem anderen zu gefallen oder seine Gunst zu erlangen.

trifft überhaupt nicht zu				trifft genau zu
□	□	□	□	□

Um mich mit anderen gut zu verstehen und gemocht zu werden, neige ich dazu, so zu sein, wie andere es von mir erwarten.

trifft überhaupt nicht zu				trifft genau zu
□	□	□	□	□

E. 2 Opinion Questionnaire

Ambivalence (Griffin-Index)
(see Questionnaires of Study 1)

Subjective Ambivalence
(see Questionnaires of Study 1)

Difficulty
(see Questionnaires of Study 1)

Certainty
(see Questionnaires of Study 1)

Need for Social Comparison
Wie interessant fänden sie es zu erfahren, was andere Besucher vor Ihnen zum Thema Nanotechnologie gesagt haben?

überhaupt nicht				sehr
□	□	□	□	□

Social Projection of Opinion
Schätzen Sie bitte, welche Meinung zum Thema Nanotechnologie die anderen Besucher im Vergleich zu Ihrer Meinung abgegeben haben.

- □ Im Allgemeinen waren die anderen Besucher der absolut gleichen Meinung wie ich.
- □ Im Allgemeinen waren hatten die anderen Besucher eine ganz andere Meinung als ich.

Self Generated Consensus
Wie viel Prozent der anderen Besucher haben Ihrer Meinung nach eine sehr ähnliche Einschätzung abgeben wie Sie selbst?

- □ 0 % waren einer sehr ähnlichen Meinung wie ich.
- □ 25 % waren einer sehr ähnlichen Meinung wie ich.
- □ 50 % waren einer sehr ähnlichen Meinung wie ich.
- □ 75 % waren einer sehr ähnlichen Meinung wie ich.
- □ 100 % waren einer sehr ähnlichen Meinung wie ich.

E. 3 Questionnaire on Feedback about Others' Opinion

<u>Similarity</u>

Ich denke, die anderen Besucher sind mir sehr ähnlich.

trifft überhaupt nicht zu ☐ ☐ ☐ ☐ ☐ trifft genau zu

Die anderen Besucher haben mit mir nur wenig Gemeinsamkeiten.

trifft überhaupt nicht zu ☐ ☐ ☐ ☐ ☐ trifft genau zu

Wenn ich an die bisherigen Besucher dieser Ausstellung denke, dann fühle ich mich dieser Gruppe sehr zugehörig.

trifft überhaupt nicht zu ☐ ☐ ☐ ☐ ☐ trifft genau zu

<u>Discrimination</u>

Die Gründe, die die anderen Besucher für Ihre Meinung haben…

…waren sehr überzeugend.

trifft überhaupt nicht zu ☐ ☐ ☐ ☐ ☐ trifft genau zu

…waren sehr relevant.

trifft überhaupt nicht zu ☐ ☐ ☐ ☐ ☐ trifft genau zu

…waren sehr schwach.

trifft überhaupt nicht zu ☐ ☐ ☐ ☐ ☐ trifft genau zu

…waren sehr intelligent.

trifft überhaupt nicht zu ☐ ☐ ☐ ☐ ☐ trifft genau zu

…waren sehr schlecht.

trifft überhaupt nicht zu ☐ ☐ ☐ ☐ ☐ trifft genau zu

<u>Psychological Discomfort</u>

Als ich die Meinung der anderen Besucher erfahren habe…

…war ich beunruhigt.

trifft überhaupt nicht zu ☐ ☐ ☐ ☐ ☐ trifft genau zu

…war ich verstört.
trifft überhaupt nicht zu — trifft genau zu
☐ ☐ ☐ ☐ ☐

…war ich glücklich.
trifft überhaupt nicht zu — trifft genau zu
☐ ☐ ☐ ☐ ☐

…war ich erstaunt.
trifft überhaupt nicht zu — trifft genau zu
☐ ☐ ☐ ☐ ☐

…war ich verwundert.
trifft überhaupt nicht zu — trifft genau zu
☐ ☐ ☐ ☐ ☐

…war ich wie vor den Kopf geschlagen.
trifft überhaupt nicht zu — trifft genau zu
☐ ☐ ☐ ☐ ☐

…war ich erleichtert.
trifft überhaupt nicht zu — trifft genau zu
☐ ☐ ☐ ☐ ☐

…war ich beruhigt.
trifft überhaupt nicht zu — trifft genau zu
☐ ☐ ☐ ☐ ☐

…war ich erfreut.
trifft überhaupt nicht zu — trifft genau zu
☐ ☐ ☐ ☐ ☐

…war ich wütend.
trifft überhaupt nicht zu — trifft genau zu
☐ ☐ ☐ ☐ ☐

…war ich erleichtert.
trifft überhaupt nicht zu — trifft genau zu
☐ ☐ ☐ ☐ ☐

Perceived Conflict

Wie sehr haben sich Ihre eigene Meinung und die Meinung der anderen Besucher unterschieden?

überhaupt nicht — sehr
☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐

E. 4 Posttest

Position

Wenn Sie sich nun entscheiden müssten, ob Sie - summa summarum - für oder gegen Nanotechnologie wären und nur diese beiden Alternativen hätten, würden Sie sich pro oder kontra Nanotechnologie entscheiden?

□ pro - dafür □ kontra - dagegen

Argument Repertoire

Sie haben nun viele Informationen zur Nanotechnologie erkundet und auch einige Expertenstatements zu Chancen, Risiken und Implikationen dieser Technologie kennengelernt.

Schreiben Sie bitte hier alle Argumente pro - also für - Nanotechnologie auf, die Sie z.B. in Form von Expertenstatements kennengelernt haben, unabhängig davon, ob Sie diese für relevant halten oder Ihnen zustimmen würden.

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Sie haben nun viele Informationen zur Nanotechnologie erkundet und auch einige Expertenstatements zu Chancen, Risiken und Implikationen dieser Technologie kennengelernt.

Schreiben Sie bitte hier alle Argumente kontra - also gegen - Nanotechnologie auf, die Sie z.B. in Form von Expertenstatements kennengelernt haben, unabhängig davon, ob Sie diese für relevant halten oder Ihnen zustimmen würden.

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Opinion Quality

Sie haben sich im Laufe des Ausstellungsbesuchs vielleicht eine eigene Meinung zum Thema Nanotechnologie gebildet. Finden Sie Nanotechnologie nun gut oder schlecht? Chancenreich oder risikoreich? Gefährlich oder vielversprechend?

Sie haben bereits einige Angaben dazu gemacht, nun möchte ich Sie bitten, dass Sie in einem offenen Statement Ihre Meinung äußern.
Bitte versuchen Sie, Ihr Statement so gut wie möglich zu begründen, beziehen Sie sich auf Informationen aus der Ausstellung. Ihr Statement sollte anderen Personen klar vermitteln, ob sie Nanotechnologie gut oder schlecht finden und warum das so ist!

Counterargument /Rebuttal Construction

Sie haben nun Ihre Gründe und Argumente dargelegt, die Ihrer Meinung zu Nanotechnologie zugrunde liegen.

Welche Argumente/Gründe könnten diejenigen Besucher haben, die einer anderen Meinung sind als Sie?

Diskutieren Sie hier bitte Grund Nr. 1:

Diskutieren Sie hier bitte Grund Nr. 2:

Diskutieren Sie hier bitte Grund Nr. 3:

Attitudes

(see Questionnaires of Study 1)

Factual Knowledge

(see Questionnaires of Study 1)

F.

Coding Schemes: Study 1 and Study 2

F.1 Reflective Judgement (Study 1 and 2)

Score	Description
0	Statements that fail to express an own opinion were coded as 0, indicating a very low level of reflexivity. Statements of this level may cite arguments both pro and con nanotechnology but Ss make no attempt to evaluate these arguments or integrate them into an own position.
1	Statements that stated an opinion (however, this opinion can be pro or con but also neutral or ambivalent) but provided no rationale at all were coded as 1. This level indicates that the Ss did not use the information of the exhibition or expert statements for expression of opinion.
2	Statements with rationale but without valid grounds for this rationale were coded as 2. Ss have made limited effort to use information and arguments from the exhibition to base their position. However, these rationales do not validly support their position or might be incoherent.
3	Statements with valid rationale but with clearly mysided argumentation and that therefore failed to integrate reasons for possible counter positions were coded as 3. These statements show that Ss did not realize that relevant arguments might result in multiple positions. Ss provide supporting arguments for their own position only. Evaluation of othersided arguments does not take place.
4	Statements with recognition and citation of counter positions but no rebuttals were coded as 4. These statements show that Ss were able to recognize that other positions may exist and to weigh both pros and cons of nanotechnology. However, a valid integration of counter positions into Ss' own opinion by means of rebuttals of counter arguments still lack in this level. Ss' own position might be supported by devaluation of the counterpositions.
5	Statements with careful rationale that evaluates both pro and cons, that shows significant recognition of counterpositions, and that incorporates also rebuttals and careful integration of counterpositions were coded as 5, finally. These statements are both comprehensible and persuasive expressions of an own position.

F.2 Counterargument and Rebuttal Construction (Study 2)

Score	Scoring Criteria
0	Statements that fail to generate othersided arguments are coded as 0.
1	Statements that generate othersided arguments but fail to discuss them at all are coded as 1. Other perspectives are cited but no attempts to critically analyze and evaluate these positions and to defend the personal opinion against counterarguments are made.
2	Statements with limited reflection on others' views are coded as 2. However, these statements engage only othersided ideas that are obvious or agreeable. Avoids challenging or discomforting ideas. No evidence of attending to others' arguments critically. Superficial refutation of own position if any. No use of counterevidence. No evidence of self-assessment can be found.
3	Statements that yield emerging reflection on othersided arguments are coded as 3. Valid counterarguments are constructed and discussed. However, others' perspectives are treated superficially. Alternative views are dismissed hastily or treated in a way that understates the conflict. Statements tend to discriminate or devaluate other perspectives. No use of counterevidence to defend the own position. No evidence of self-assessment can be found.
4	Statements that show thoughtful reflection on othersided arguments are coded as 4. These statements engage challenging ideas and investigate others' arguments in a limited but thoughtful way. Evidence is used to successfully refute own position. Some evidence of reflection of own position and self-assessment. Limited integration of counterarguments into own position. Begins to relate alternative views to qualify own analysis.
5	Statements that show respectful analysis of others' arguments and thoughtful justification of own position are coded as 5. Clearly justifies own view while respecting views of others. Provides counterevidence to defend own position. Analysis of other position is nuanced and respectful. Clear evidence of reflection on own position and self-assessment. Integration of counterarguments into own position.