Adaptive Expertise in

Solving Technical-Medical Problems

Master Thesis by

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Summary

Routine experts only show expert performance and efficient problem solving on familiar, routine problems. Adaptive experts, however, balance efficiency with innovation and are able to adapt flexibly to non-routine, non-familiar problems. Adaptive experts have extensive conceptual knowledge, higher metacognition, are innovative and flexible, show determination and a tolerance to ambiguity, and identify themselves positively with their domain. Technical-medical expertise, in which experts systematically use medical and technological expertise to improve healthcare through innovation, is arguably similar to adaptive expertise.

The similarity between problem solving strategies of technical-medical experts and the problem solving strategies that constitute adaptive expertise was investigated through qualitative (verbal) analysis. Technical physicians solved a technical-medical problem case while thinking aloud. The verbalizations were recorded, transcribed, segmented, coded and analysed for patterns. The methodology was tested during a pilot experiment.

Overall, the results show large proportions of efficiency and metacognition, a moderate amount of decision making and small proportions of innovation and mentioning knowledge. The problem solving strategies of technical-medical experts are at least superficially similar to the problem solving strategies that constitute adaptive expertise, but it cannot be concluded whether TME is structurally more similar to AE than to RE. More research is needed to investigate the structural similarities. Unfortunately, no conclusions could be drawn about the personality and attitudes of the technical physicians.

Possible follow-up studies may focus on problem solving strategy proportions of adaptive and routine experts, the nature of flexibility and the attitudes and personality traits of technical physicians.

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1. Introduction

Expertise, or expert performance, is defined by Ericsson and Lehmann (1996) as "consistently superior performance on a specified set of representative tasks for a domain" (p. 277). This general definition is an example of *routine expertise (RE)*; some individuals, however, have *adaptive expertise (AE)*, which adds an innovative dimension to RE (e.g. Schwartz, Bransford & Sears, 2005). Both types of expertise are described in more detail in this paper. After this, the expertise of a new type of healthcare professional, the *technical physician*, will be described and compared to AE through qualitative analysis. This research is focused on the *technical-medical expertise (TME)* of technical physicians and its similarity to AE.

Expert level of performance is typically only reached by individuals after years of extensive experience in a particular domain (Ericsson, 2008; Ericsson & Lehmann, 1996). According to Ericsson (2008) and Ericsson and Lehmann (1996), the key for reaching expert performance lies in deliberate practice, which is the deliberate attempt of an individual to increase his or her performance by avoiding "arrested development associated with automaticity" (Ericsson, 2008, p. 991). However, the variance in performance explained by deliberate practice is limited and varies per domain, ranging from 26% for games and less than 1% for professions (Macnamara, Hambrick and Oswald, 2014). This might be because of less predictable activities in professions or different levels of expertise and experience prior to education or jobs.

Through their extensive experience, experts have acquired a large body of knowledge about their domain (Ericsson & Lehmann, 1996; Robertson, 2001; Schraagen, 1994) that allows them to perceive large meaningful patterns and represent problems at a deep and principled level (Chi, Glaser & Farr, 1988).

Furthermore, they have developed automated procedures to deal fast and accurately with routine problems in their own domain (Chi *et al.*, 1988; Robertson, 2001), showing, among others, superior performance in short-term and long-term memory, and self-monitoring skills (Chi *et al.*, 1988).

Two important things should be noted. First, there is an apparent restriction of expert performance to one particular domain, resulting in far less optimal performance in other domains (Chi *et al.*, 1988; Robertson, 2001; Schraagen, 1993; Schraagen, 1994). For example, a heart surgeon will not show his usual performance should he have to perform plastic surgery. Second, superior expert performance seems to be only possible for routine problems. The heart surgeon will for instance perform better on common surgeries than on less common surgeries. Indeed, as discussed in De Groot (1978) and Robertson (2001), when confronted with non-routine, non-familiar problems, the performance of experts is generally similar to that of novices.

This decline in problem solving performance for non-routine problems does not hold for all types of expertise, however, as some experts are able to adapt flexibly to the different context. Schwartz *et al.* (2005) identified two distinct dimensions of learning and transfer for experts: the *efficiency dimension*, wherein individuals use, retrieve and apply knowledge to solve problems accurately, rapidly and consistently, and the *innovation dimension*, wherein individuals see problems as opportunities for knowledge creation (Mylopoulos & Woods, 2009; Mylopoulos & Regehr, 2009) and can rearrange their problem solving approach when necessary (Paletz, Kim, Schunn, Tollinger & Vera, 2013; Schwartz *et al.*, 2005).

As described by Mylopoulos and Woods (2009), Paletz *et al.* (2013) and Schwartz *et al.* (2005) experts who only use the efficiency dimension to solve their problems are called *routine experts*. In other words, routine experts use their extensive knowledge of their domain of expertise to efficiently solve familiar problems that do not require innovation.

On the other hand, experts who use the efficiency dimension as well as the innovation dimension are called *adaptive experts*. These experts balance efficiency and innovation when solving problems, and are therefore able to perform better than routine experts on unfamiliar problems that require innovative thinking to be solved (Mylopoulos & Woods, 2009; Mylopoulos & Regehr, 2009; Paletz *et al.*, 2013; Schwartz *et al.*, 2005). The dimensions and their resulting types of expertise are depicted in Figure 1.

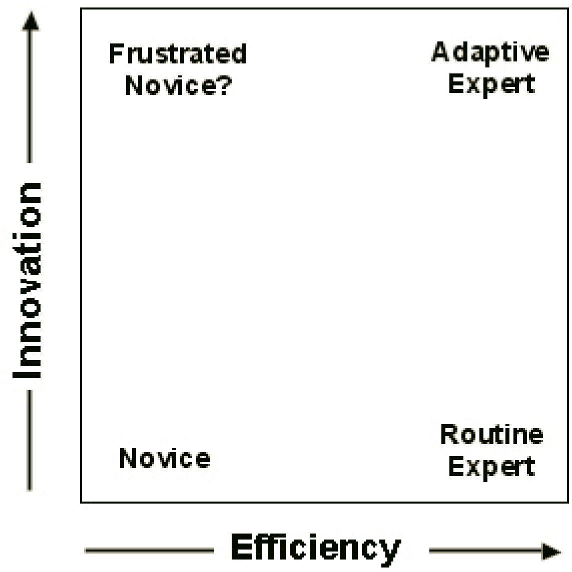


Figure 1. Innovation and efficiency dimensions for learning and transfer. Retrieved from Schwartz, D. L., Bransford, J. D., & Sears, D. (2005). Efficiency and Innovation in Transfer.

Adaptive experts transfer their knowledge to novel situations at the right time and in the right way (Paletz *et al.*, 2013). They are able to work in an 'optimal adaptability corridor' by balancing efficient use of knowledge with the creation of new knowledge (McKenna, Colgate, Olson & Carr, 2006; Mylopoulos & Regehr, 2009; Schwartz *et al.*, 2005).

Influenced by the work of Schwartz *et al.* (2005), William Neeley (2007) proposed a new theory of adaptive expertise in design that he named the *Theory of Adaptive Design Expertise (TADE)*. In TADE, AE of designers consists of three dimensions. The first dimension is the *active*, which is the ability of designers to think actively and independently.

This dimension is essentially intellectual development in the context of design thinking, which ranges from *(re)using* things to *altering* things to *creating* things (Neeley, 2007). The second dimension, the *abstractive*, consists of *reflective practice*, which is the ability to reflect upon the designing process, and *reflective abstraction*, which is the development of increasingly sophisticated understandings of the design (Neeley, 2007). These understandings are abstractions that range from *products* (i.e. recognition of good and bad designs through trial-and-error) to design *processes* (i.e. recognition of its stages) to design *paradigms* (i.e. full understanding of design concepts). The *adaptive* dimension, the third dimension of TADE, is characterised as the ability to shift accurately and flexibly between and along the first two dimensions (Neeley, 2007). Figure 2 shows an overview of TADE.

Similar to the framework of Schwartz *et al.* (2005), a major component of TADE is the emphasis on flexibility and adaptability (these terms are used interchangeably in this paper). While according to Schwartz and colleagues (2005) adaptive experts are able to balance efficiency with innovation when the situation asks for it, Neeley (2007) argues that they are able to flexibly switch between the right levels of intellectual activities and design abstractions for the particular (design) situation.

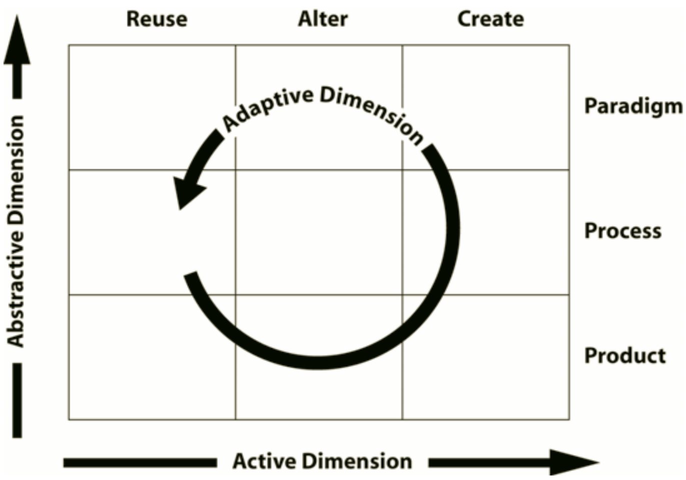


Figure 2. Neeley's Theory of Adaptive Design Expertise. Retrieved from Neeley, W. L. (2007). Adaptive Design Expertise: A Theory of Design Thinking and Innovation.

Another explanation for the superior performance of adaptive experts in flexible problem solving is that they have higher metacognition than routine experts. Adaptive experts are willing to question their initial assumptions (Hatano & Inagaki, 1984) and are able to recognise when problems do not 'fit' within their extensive, well-organised and highly differentiated schemas, and consequently engage in a more extensive search for solutions (Robertson, 2001). Furthermore, adaptive experts assess and monitor their own understanding and performance, seek feedback and recognize when their knowledge is insufficient (Fisher & Peterson, 2001).

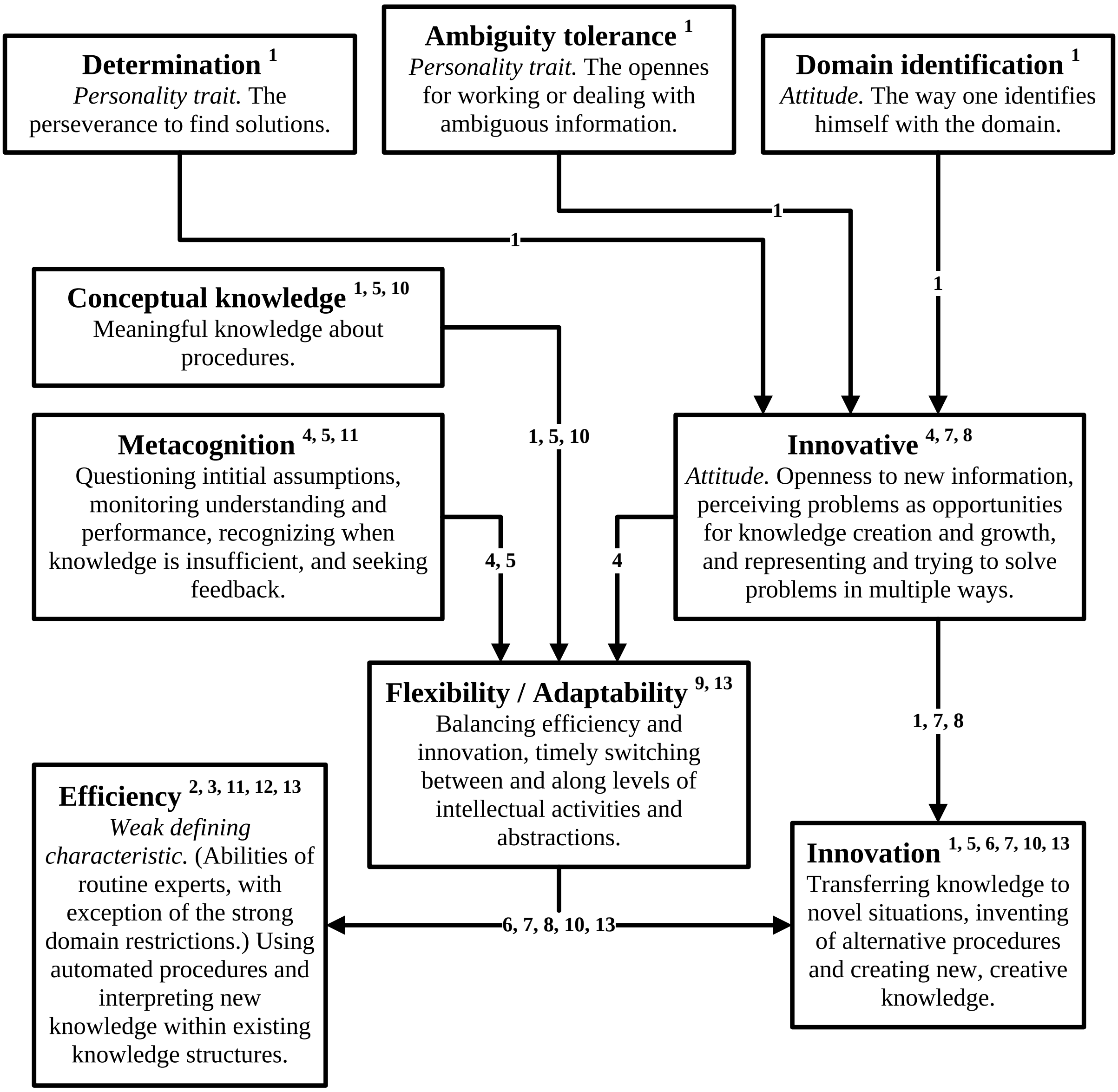
However, 'normal' experts have extensive schemas and high metacognition as well (Ericsson & Lehmann, 1996; Robertson, 2001). This is also suggested by Schraagen (1994), who mentions that experts are "able to outperform novices when confronted with novel problems simply by invoking some kind of knowledge, other than automated perceptual skills, that novices do not possess" (p. 3). Furthermore, Brophy, Hodge and Bransford (2004) and Robertson (2001) point out that experts (in general) are better at finding new solutions than novices, which implies that routine experts can show flexibility as well and adaptive experts just do a better job in this.

Thus, it seems that a key factor lies in whether the expert engages in a thorough search for solutions or not, which implies a certain attitude of adaptive experts towards problem solving that routine experts lack. Individuals who are located high on the innovation dimension see problems as opportunities for knowledge creation (Mylopoulos & Woods, 2009; Mylopoulos & Regehr, 2009) and growth (Fisher & Peterson, 2001). Fisher and Peterson (2001) also suggest that adaptive experts are open to new information, represent problems as solvable in multiple ways and are willing to try these multiple approaches. They perceive knowledge as non-static and keep searching for new information (Fisher & Peterson, 2001). This al points towards an innovative attitude of adaptive experts.

Giyoo Hatano and Kayoko Inagaki (1984) were, to my knowledge, the first to make the distinction between routine experts and adaptive experts. They claimed that conceptual knowledge is the key for flexible problem solving: while routine experts have very good procedural knowledge by being able to perform a skill faster and more accurately, adaptive experts also develop conceptual knowledge that allows them to cope with unexpected flaws in their current procedure (see Brophy *et al.* (2004) and Paletz *et al.* (2013) as well). Furthermore, conceptual knowledge gives meaning to procedures and yields criteria for the selection or even invention of possible alternative procedures (Hatano & Inagaki, 1984; Paletz *et al.*, 2013). This certainly is in line with the innovation dimension of Schwartz *et al.* (2005) and the adaptive dimension of Neeley (2007), which both allow for flexibility.

However, Brophy *et al.* (2004) argue having extensive conceptual knowledge does not guarantee the production of innovative ideas. They mention some personality traits the experts should have in order to be motivated to generate creative ideas (i.e. have an innovative attitude). First, the expert should be willing to work with ambiguity, and second, they must have some measure of determination to find solutions (Brophy *et al.*, 2004). They furthermore argue that the extent of AE is influenced by the way experts identify themselves with the domain, since this may interact with their innovative abilities within this domain (Brophy *et al.* (2004). It seems likely that a positive identification with the domain will result in higher innovative abilities.

The characteristics of AE are summarized in Figure 3. The corresponding literature is provided per characteristic and per link between characteristics. Clearly, flexibility is an important aspect of AE, located at the top of the hierarchy. Efficiency is labelled as a ‘weakly defining characteristic’, because it is shared with RE. The rest can be considered ‘strongly defining characteristics’, since they define AE and not RE. Of course, the consisting factors of efficiency could be further analysed as well, but that is beyond the scope of this research.



References:

1. Brophy *et al.* (2004)
2. Chi *et al.* (1988)
3. Ericsson & Lehmann (1996)
4. Fisher & Peterson (2001)
5. Hatano & Inagaki (1984)
6. McKenna *et al.* (2006)
7. Mylopoulos & Regehr (2009)
8. Mylopoulos & Woods (2009)
9. Neeley (2007)
10. Paletz *et al.* (2013)
11. Robertson (2001)
12. Schraagen (1994)
13. Schwartz *et al.* (2005)

Figure 3. Characteristics of Adaptive Expertise

In the last decades, a large amount of new or improved medical technologies has been developed in the Netherlands, a positive trend that is likely to continue (IGZ, 2008). The drawback of this is that new risks for patient safety emerged in the form of insufficient training in these new medical technologies, underestimation of potential risks, and insufficient safety management in general (IGZ, 2008).

To tackle this drawback, new professionals were needed who are skilled in both medical and technological domains, and who could bridge the gap between healthcare and technology (IGZ, 2008). The study *Technical Medicine (TM)* at the University of Twente bridges this gap by training students to become this new kind of professional: the technical physician. TM can be regarded as a bridge between medical technology (e.g. Biomedical Engineering) on the one hand, and classical medicine on the other (University of Twente, 2014).

In practice, this means that technical physicians continuously have to work within these two domains. They may therefore be considered adaptive experts, since routine experts would be restricted to one domain only (Chi *et al.*, 1988; Robertson, 2001; Schraagen, 1993; Schraagen, 1994). Furthermore, technical physicians always have to deal with problems that are non-routine to medicine as well as medical technology. Since routine experts would show lessened performance on non-routine problems (De Groot, 1978; Robertson, 2001), technical physicians could again be classified as adaptive experts.

Technical physicians design, improve and implement medical technology to develop and improve diagnostics and therapeutics of patients (University of Twente, 2013; University of Twente, 2014). They use an engineering approach that systematically solves problems based on empirical evidence (University of Twente, 2013).

Their official way of working, the *technical-medical procedure (TMP)*, is very similar to the problem solving-focused *regulative cycle* of Van Strien (1997). This cycle consists of five steps: 1) problem identification, 2) problem diagnosis, 3) planning for a solution to the problem, 4) intervention, in which the plan is implemented in practice, and 5) evaluation (Van Strien, 1997). The TMP generally consists of these five steps as well, while adding a sixth step (concluding and reporting) between intervention and evaluation. This clearly indicates that the TMP has a strong focus on problem solving.

TM is strongly and explicitly focused on innovation, through the development of new, innovative ideas and interventions (University of Twente, 2013). While this is primarily the creation of innovative solutions, it implies that during their education technical physicians develop an innovative attitude. This supports the assumption that technical physicians are adaptive experts, since an innovative attitude is a characteristic of AE (Fisher & Peterson, 2001; Mylopoulos & Regehr, 2009; Mylopoulos & Woods, 2009).

All of the above constitutes TME: a new, unique domain of expertise in which medical expertise and technological expertise are combined for systematically solving non-routine problems in a technical-medical domain, in order to improve diagnostics and therapy of patients through innovation.

Arguably, TME is a type of AE for technical physicians, similar to TADE being a type of AE for designers (Neeley, 2007), since technical physicians have to deal with non-routine problems within multiple domains and have developed an innovative attitude during their education. Furthermore, much emphasis is placed on critical self-reflection skills of TM-students during their education (University of Twente, 2013). Arguably, this results in high metacognition skills, which is one of the strong defining characteristics of AE as well.

Indeed, TME seems to be adaptive in nature. Neeley (2007) claims that the design models existing at that point failed to take the adaptive nature of designing into account, which he argues are "the essence of the creative act in which design resides" (p. 3). This implies that this adaptive or flexible nature is an important part of design. Since a part of the TMP consists of design as well (University of Twente, 2013; University of Twente, 2014), this should at least partly be true for TME. However, at this point it remains unclear whether the active and abstractive dimensions of TADE (Neeley, 2007) might be reflected in TME as well.

Furthermore, balancing efficiency and innovation is arguably similar to combining the two major characteristics of TME described earlier: the systematic approach and the explicit focus on innovation (University of Twente, 2013). Using a systematic approach repeatedly is likely to result in efficient, but routine, procedures. And, as eloquently put by Neeley (2007): "It is through routine that expertise can come to actually hinder innovation" (p. 61). For technical physicists to still be able to be innovative, balance needs to be found between this systematicity and the focus on innovation, much like adaptive experts have to balance the efficiency and innovation dimensions. Thus, flexibility/adaptability seems to be a strong defining characteristic for both AE and TME.

However, it is currently not known how the flexible and innovative nature of TME manifests itself in problem solving strategies, since this kind of expertise has never been scientifically tested before. Due to the resemblance between TME and AE, it is likely that this manifestation will be similar to the problem solving strategies of adaptive experts, but this remains to be tested. Also, it is not known whether technical physicians are determined, willing to deal with ambiguity and identify themselves positively with the technical-medical domain, although according to Brophy *et al.* (2004) these are three enabling factors for an innovative attitude.

The primary goal of my research was to fill this knowledge gap by comparing the problem solving strategies of technical-medical expertise with those of adaptive expertise. In this research, ‘problem solving strategies’ was operationalized as the activities during solving problems that reflect expertise characteristics. By assessing these activities of technical physicians, more insight is provided in the characteristics that constitute TME and whether these are similar to those that constitute AE. My main research question was as follows: ‘To what extent are problem solving strategies of technical-medical experts similar to the problem solving strategies that constitute adaptive expertise?’ Apart from filling this knowledge gap, I aimed to provide a scientific basis for technical-medical expertise and, more generally, for expert problem solving in domains where technology and healthcare interact.

To my knowledge, this research is the first exploratory study on TME. I investigated it through qualitative verbal analysis of verbalizations of TM-graduates who had to solve a technical-medical problem case while thinking aloud. According to Chi (1997), this method is especially suited for this type of research, in which pre-defined models (such as Figure 3) and exploratory data interpretations are combined. The similarity will be considered substantial when all strongly defining characteristics of AE, as summarized in Figure 3, are represented in the verbalizations of TM-graduates, and increasingly less substantial when these verbalizations contain less strongly defining AE-characteristics and more other characteristics.

2. Pilot experiment

To compare technical physicians with AE, I needed to assess their way of working. To do this, I presented a technical-medical problem case and asked them to solve it while thinking aloud. This methodology was inspired by the work of Hutchison and McKenna (2007), who described a method for assessing students' use of innovation through design problems. Subsequently, the general problem solving strategies were identified through qualitative analysis. The methodology was first tested with a pilot experiment.

2.1 Method pilot experiment

2.1.1 Participants

A total of 4 Dutch TM-students, who were in the last phase of graduation in MII (see below), participated in the pilot, 2 male and 2 female, with age ranging from 24 to 27. All participants gave their informed consent prior to participation, and the entire procedure was ethically approved by the Ethical Committee of the faculty of Behavioural Sciences at University of Twente.

2.1.2 Materials

2.1.2.1 Technical-medical problem cases

I formulated (in Dutch) two technical-medical problem cases, one for each specialization of the TM-master. Both topics were relevant in healthcare at the time. For the specialization *Medical Imaging & Intervention (MII)*, which mostly deals with advanced techniques for imaging and localization, robotics and minimal invasive technology (www.utwente.nl/tg/education/mastertracks/mii), the problem was to think of a concept that solves two major restrictions of transrectal ultrasound (TRUS)-guided biopsy of the prostate.

The specialization *Medical Sensing & Stimulation (MSS)* deals with diagnosis and processing of medical signals (http://www.utwente.nl/tg/education/mastertracks/MS). The corresponding problem was to think of a concept that monitors risks of mechanical ventilation and is tailored to the needs of each individual patient. Both cases were conceived and checked for accuracy by two TM-teachers of the concerned specialization.

As advocated by Hutchison and McKenna (2007), I aimed for problem cases solvable in 60 minutes and took care to choose and formulate the cases as structurally similar as possible. Both case descriptions consisted of two sentences introducing the subject, two sentences describing the main restrictions of the subject and one sentence describing the negative consequences of these restrictions. The instructions (in Dutch) both started with "Your assignment is as follows: conceive and describe a concept …" and the descriptions of the procedure were exactly similar. Following Someren, Barnard and Sandberg (1994), I aimed for a case difficulty that requires participants to be creative in their approach and does not allow them to rely on automated procedures only.

Hutchison and McKenna (2007) allowed their participants to use information that the researchers themselves had identified as relevant beforehand. I was, however, concerned that this might undermine the natural problem solving process and innovative tendencies of the participants, since providing certain information might influence the course of thinking (Someren *et al.*, 1994). On the other hand, without providing background information, the participant might get stuck in an early stage of the problem solving process when he is mostly unfamiliar with the subject. I therefore opted for providing limited information. I handpicked two review articles, which did not contain solutions to the problem, one for each technical-medical case. These articles were Aigner *et al.* (2010) for the MII case and Richard, Lefebvre, Tassaux and Brochard (2011) for the MSS case.

2.1.2.2 Questionnaire

A (Dutch) questionnaire with five items was developed for assessing the background of the participants and their relevant experiences during the experiment. The first item asked about familiarity with the problem subject prior to the experiment, to check for prior knowledge. The next two items were 4-point Likert scales that checked for the similarity of the case to problems encountered during their work (internships) and during their education. The fourth item asked if they found the *article* to be useful and the fifth item if they were content with their results. Participants were given the option to give a written explanation for each answer.

2.1.2.3 Practice problem

The Tower of Hanoi problem (see Robertson, 2001) was used as practice problem to familiarize participants with thinking aloud (Hutchison & McKenna, 2007; Someren et al., 1994), see Figure 4. The objective was to bring both rings to pin C in three steps, moving only one ring at a time and without placing the larger ring on top of the smaller ring, while thinking aloud.

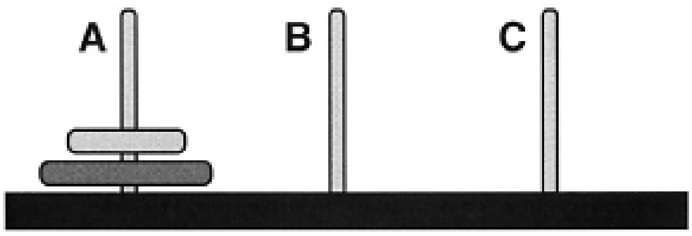


Figure 4. Simple Tower of Hanoi practice problem. Retrieved from Robertson, S. I. (2001). *Problem Solving*.

2.1.2.4 Voice recorder

Audio was recorded using the H1 Handy Recorder version 2.0 of the company ZOOM (www.zoom.co.jp/products/h1).

2.1.3 Procedure

First, the participant was informed about the goals of the research and the procedure and gave his informed consent. He was provided with water, blank paper, pens and highlighters, and was seated in a quiet room with only the experimenter.

As advised by Someren *et al.* (1994), the think-aloud instruction (in Dutch) was held simple: “Try to verbalize everything that goes through your mind.” Furthermore, the experimenter should not interfere in any way and should only prompt the participant when he falls silent (Someren *et al.*, 1994). During the main case, the experimenter therefore only spoke when necessary, to prompt the participant by saying (in Dutch): “Try to keep thinking aloud.”

The participant received the think-aloud instruction and solved the practice problem while thinking aloud. Feedback was given on the verbalization style afterwards if necessary. Then, the think-aloud instruction was repeated, and the participant received the case and the corresponding review article. He was instructed to describe the solution concept on the document containing the case and to highlight any information he uses from the article. The blank paper could be used for notes and sketches. The participant then proceeded to solve the case while thinking aloud. All verbalizations were recorded using the H1 recorder. After the participant felt he was ready, the recording was stopped and he filled in the questionnaire. Afterwards, any remaining questions were answered by the experimenter.

2.1.4 Analysis

2.1.4.1 Transcription

Each recording was transcribed “as verbatim as possible” (Someren *et al.*, 1994, p. 45). In line with Someren *et al.* (1994), I included every verbalisation and mentioned every interrupting prompt, question or event. All silent periods were also included in the transcriptions.

2.1.4.2 Verbal analysis

For the analysis, I used the *verbal analysis* approach, which is described by Chi (1997) as the quantification of qualitative data derived from verbal utterances, by reducing the subjectiveness of qualitative coding through drawing relations between these verbal utterances. Qualitative data is coded, and the codings are then analysed quantitatively to identify the patterns (Chi, 1997). The description of the participants' solution(s) was not analysed since I am mainly interested in the process towards the solution.

In the more traditional *protocol analysis* a strictly top-down approach is used, in which the verbal report is matched with a predefined model (Chi, 1997; Someren *et al.*, 1994). Verbal analysis, however, utilises an interaction between top-down and bottom-up approaches by allowing modifications to the predefined model based on the verbal data itself (Chi, 1997). Since this research is exploratory in uncovering the nature of TME, starting with a predefined AE model (top-down approach) and modifying it based on the actual verbalisations of technical physicians (bottom-up approach) makes sense. I therefore opted for verbal analysis instead of protocol analysis.

2.1.4.3 Coding scheme

The coding scheme used for analysing the verbal data (i.e. segmenting and coding) was built and tested during the pilot. It generally consisted of three parts: identification of non-relevant data, segmentation of the relevant data and coding of the relevant data. The non-relevant data consisted of all verbalisations that did not add to solving the case, such as questions about the procedure and responses to prompts. Using a criterion to filter out non-relevant verbalisations is the method of choice of Chi (1997).

The unit of analysis was set to one or more phrases or sentences that reflect *one* topic, with segments before and after this segment reflecting different topics, because Chi (1997) argues that using semantic features, such as ideas, argument chains or topics, as boundaries for the units of analysis yields more meaningful segments than using non-content features, such as pauses or changes in activity. As advocated by Chi (1997), the codes were developed top-down (based on the AE characteristics shown in Figure 3) as well as bottom-up (based on the verbal data).

My supervisor and I tested the coding scheme three times, once on each participant transcription. We both used the software Atlas.ti 7 for segmenting and coding the transcriptions. Our agreement and inter-coder reliability were calculated were possible (Chi, 1997; Someren *et al.*, 1994). The coding scheme was revised after each test, up to a fourth version (coding scheme V4).

2.2 Results pilot experiment

2.2.1 General results

Participant 4 expressed discomfort with thinking aloud; therefore no verbalisations were recorded and no transcription was made for this participant. All four participants did write down a solution at the end of the experiment. Table 1 gives an overview of the primary results of the pilot. The average completion time was 43 minutes, with a standard deviation of 7.0.

Overall, no issues were found with the wording, interpretation and difficulty of the questionnaire, the practice problem and the technical-medical case. It was found that the MII review article (Aigner *et al.*, 2010) contained some detailed suggestions that could be used as a solution to the case, which were used by all participants. Furthermore, all participants initially thought that the review article was the main source for the solution. Lastly, no relevant information could be extracted from the review article highlights.

Table 1. *Primary Results of Pilot*

Participant	Case type	Case familiarity	Completion time (min.)	Satisfaction	Article Usefulness	Work field similarity	Education similarity
1	MII	Yes	36	No	No	Large	Large
2	MII	No	53	Yes	Yes	Small	Large
3	MII	No	46	No	Yes	Very small	Very small
4	MII	Yes	37*	No	Yes	Very small	Large

* Estimated value, due to lack of recording.

2.2.2 Coding scheme results

Table 2 shows the results of our tests of the coding scheme. For coding scheme V1, no inter-coder reliability could be calculated due to our disagreement in segmentation. Also, no segmentation agreement was calculated for V3 since the segmentation was only performed by me. Because of the low frequency of trait and attitude codes, no inter-coder reliability could be calculated for these codes.

Activity codes, personality trait codes and attitude codes were separated from each other, since almost all segments could be coded as activities, and attitude and trait codes could be assigned on top of activity codes. Large, general codes such as innovation, efficiency and metacognition were split up into smaller codes, as a large amount of segments were coded with these.

2.3 Discussion pilot experiment

In the pilot experiment, the methodology of this research was tested. The results indicate that, overall, only minor changes are needed to improve the materials and procedures, while the resulting coding scheme has been developed up until moderate reliability with a Cohen's Kappa of .602 (Landis & Koch, 1977; Someren *et al.*, 1994).

Table 2. *Results of Testing the Coding Scheme*

	Coding scheme V1	**Coding scheme V2**	**Coding scheme V3**	**Coding scheme V4**
Primary modifications (compared to prior version)	-	Separation between activities, traits and attitudes. Large codes split up. Miscellaneous code added. Flexibility code removed. Declarative and procedural knowledge codes added.	Segmentation rules improved. Definitions of innovation, metacognition, efficiency and determination codes improved. Procedural knowledge code removed.	Definitions of innovation, efficiency and knowledge codes improved. Additional step of checking background participant added.
Segmentation agreement (%)	51.5	70.3 (before discussion) 100.0 (after discussion)	-	-
Coding agreement (%)	47.1	43.0 (activities) 0.0 (traits) 25.0 (attitudes)	68.3 (activities) 100.0 (traits) 28.6 (attitudes)	-
Inter-coder reliability (Cohen's Kappa)	-	.335 (activities)	.602 (activities)	-

The wording, interpretation and difficulty of the practice problem and the technical-medical cases seem to be good, as no issues were found. In line with my aim, the cases are solvable in less than 60 minutes. They also seem to be representative of TM, as most participants judged it to be similar to their education. The low ratings of similarity with their work field are not surprising, since all participants were still studying during the pilot and only participant 1, who judged the similarity to be 'large', had an internship on a similar topic. Furthermore, participants came up with different types of solutions, which implicates that the cases are solvable in multiple ways. This is likely to support innovative thinking, since perceiving problems as solvable in multiple ways is part of the innovative attitude (Fisher & Peterson, 2001; Mylopoulos & Woods, 2009; Mylopoulos & Regehr, 2009), and is therefore not an issue. Thus, the cases, as well as the practice problem, do not need to be modified for the main experiment.

Some important issues were found through the participants' usage of the review article. Participants were under the impression that their solutions could be found in the article. They all started reading almost immediately. However, most of the participants judged the article to be useful, which implicates that its removal is not a viable option; although this is arguably the result of the fact that, wrongfully, the MII article still contained some solution suggestions. Thus, a different MII article is needed that does not have these solution possibilities and the review articles should be presented at a later point to the participants to assess their prior knowledge and their unsupported problem solving strategies. To be on the safe side, it is probably also wise to include a remark in the instructions that the article does not contain solutions, and to examine the MSS article again more thoroughly. Furthermore, since highlighting information in the articles was found to be redundant, this will be removed from the procedure.

Two things were found lacking with the questionnaire. First, an item should be added in which the participant is asked about his graduation time, since this will give an estimation of the participants' relevant experience. And secondly, an item should be added that asks the participant whether he used the same problem solving procedure as he would normally use in the workplace. This will provide an estimation of both the representativeness of the technical-medical case and the prior knowledge of the participant.

The coding scheme has now been developed up to a point that it should be quite representative of TME. The AE activities are complemented by activities apparently part of TME, which were found in the data but could not be assigned to any of the AE activities. The activity codes form a complete set for coding each segment, wherein all AE strategies are represented. One exception is flexibility, which code was removed from the coding scheme.

Since flexibility is primarily an interaction between efficiency and innovation (Schwartz *et al.*, 2005), it makes sense to look at the interplay between segments coded with efficiency and innovation, rather than to try to code segments with flexibility. Thus, while the main data will be searched for signs of flexibility, as this is part of my research goal, no actual flexibility codes will be assigned.

Regarding the inter-coder reliability, Someren *et al.* (1994) argue that Kappa should be above .700 for a coding scheme to be acceptable, implicating that the reliability of my coding scheme with a Kappa of .602 is too low for use. However, due to time restraints and the fact that all pilot data had been used (participant 4 did not have a transcription), further improving the coding scheme was not possible. However, V4 is likely to have a slightly higher reliability due to resolving the issues found during testing V3. Furthermore, a Kappa between .410 and .600 has been considered as moderate and values between .610 and .800 as substantial (Landis & Koch, 1977), which would mean the reliability of V4 might just be considered as 'substantial'.

One persisting source for coding disagreement was determining which knowledge was 'new' for the participants and which knowledge was not. Chi (1997) argues that to combat the ambiguity of coding, one should always take context around the particular segment into account. So, in order to determine whether a particular segment contains new or prior knowledge, I should look at the background of the participant. Thus, an additional step was added to V4, in which the background of the participant was assessed before coding by checking his questionnaire results.

3. Main experiment

After the pilot, the main experiment was carried out to compare the expertise of graduated, working technical physicians with adaptive expertise. Some modifications have been made to the methodology based on the findings in the pilot, as described below.

3.1 Method main experiment

3.1.1 Participants

A total of 9 Dutch TM-graduates, 2 male and 7 female, took part in the main experiment. Their age ranged from 26 to 29. Three participants were involved in education at University of Twente as PhD-students, one participant worked in a research facility and the rest was working as PhD-students in hospitals across the Netherlands. Three participants graduated in MSS, the other six participants graduated in MII. All participants gave their informed consent prior to their participation. The entire procedure was ethically approved by the Ethical Committee of the faculty of Behavioural Sciences at University of Twente.

3.1.2 Materials

No changes were made to the practice problem, of which the original Dutch version is showed in Appendix I. The same H1 Handy Recorder 2.0 used in the pilot was used in the main experiment as well. The wording of the technical-medical cases was kept unchanged as well, since herewith no issues were found during the pilot, although the procedure description below the objective was changed according to the modifications made to the procedure (see next section). See appendices II and III for the original Dutch versions of the MII and MSS cases, respectively.

Since the original MII review article contained some solution suggestions, I chose a new review article as a replacement (Raja, Ramachandran, Munneke & Patel, 2006). The MSS review article (Richard *et al.*, 2011) did not need to be replaced, as no solution suggestions were found after a second examination.

The questionnaire was expanded with two more items. First, an item that asked the participant about his time of graduation, which can be used to estimate the participant's work experience. Second, an item that asked the participant to what extent the problem solving procedure used during the experiment is similar to the procedure he would *normally* use for technical-medical problems. This will add another dimension to the estimation of the extent of representativeness of the technical-medical problem cases used during the experiment. The original Dutch questionnaire used in the main experiment is shown in Appendix IV.

3.1.3 Procedure

The procedure of the main experiment differed in a few ways from the pilot procedure. First, as mentioned above, the option to highlight text was removed, as well as the instruction to do so. Second, since the cases were found to be solvable in less than one hour, a time restraint of 60 minutes was implemented and added to the instructions. The experimenter reminded about the time at 30, 45 and 55 minutes. Third, the review article was presented after 15 minutes, not at the start of the experiment, and participants were not told beforehand that they would receive it in order to assess their prior knowledge and unsupported problem solving. When presenting the article, the experimenter remarked that it only contains more information, not solutions to the problem. And fourth, the experimenter explicitly mentioned during the instructions that the participants are not assessed personally, hoping to avoid uncomfortableness as experienced by participant 4.

3.1.4 Analysis

Each recording was transcribed in the same way as in the pilot. As during the pilot, the verbal analysis approach (Chi, 1997) was used. The coding scheme V4, developed during the pilot and (the original Dutch version) shown in Appendix V, was used to segment and code the transcriptions. The actual segmenting and coding was again done in Atlas.ti 7. Although Chi (1997) argues to repeat the entire analysis process, this was not possible due to time restraints.

3.1.4.1 Reduction and segmentation

The first steps described by Chi (1997) are to reduce and segment the verbalizations. As determined in the pilot, this was done by identifying ‘non-content’ data that did not add to solving the case. This was also the first step described in V4. This was followed by the segmentation of the relevant verbalizations. The unit of analysis was kept to one or more phrases or sentences that reflect one topic, as described in detail in V4 and earlier in this paper.

3.1.4.2 Operationalizing coding scheme

The development of a coding scheme is step 3 of verbal analysis, while operationalizing (i.e. reducing the ambiguity) this coding scheme is step 4 (Chi, 1997). Both of these steps were performed during the pilot, but a persisting issue during operationalizing was determining which knowledge was ‘new’ for participants. To resolve this, the third step in V4 was to examine the background of the participant by looking at the following questionnaire results: 1) familiarity with the topic, and 2) similarity with the technical-medical work field and education.

3.1.4.3 Coding

After segmenting the data and examining the participant's background, each segment was coded. First, each segment was assigned one activity/strategy code. These codes represent the AE characteristics *efficiency* ('Integrates New Knowledge' and 'Uses Familiar Procedures'), *innovation* ('Conceives New Knowledge' and 'Conceives New Solutions'), *metacognition* ('Is Self-Critical' and 'Wants Feedback') and *conceptual knowledge* ('Names Conceptual Knowledge'), as well as the non-AE characteristics *declarative knowledge* ('Names Declarative Knowledge'), *decision making* ('Makes Procedure Decision'). V4 also contained a code for segments that did not fit into any of these categories ('Miscellaneous').

Second, after each segment was assigned an activity code, each segment was checked for the AE personality traits shown in Figure 3: *determination* ('Trait - Determination') and *ambiguity tolerance* ('Trait - Ambiguity Tolerance' and 'Trait - Ambiguity Intolerance'). And third, after checking all segments for personality traits, each segment was checked for the AE attitudes shown in Figure 3: *innovative* ('Attitude - Innovative' and 'Attitude - Uninovative') and *domain identification* ('Attitude - Positive Domain Identification' and 'Attitude - Negative Domain Identification'). Note that while each segment was assigned an activity code, not all segments were assigned a personality or attitude code.

3.1.4.4 Depicting results

After coding the segments, and in accordance with step 5 of verbal analysis (Chi, 1997), I depicted the primary results to find patterns in the data more easily, which is also the sixth step of verbal analysis (Chi, 1997). Relative frequencies of the activity codes per participant were depicted with pie charts per participant and with box plots per activity code. I opted for relative frequencies (proportions) rather than absolute frequencies, since the completion times and segment amounts were different for each participant.

To give an indication of the length of each participant, these completion times and segment amounts were presented next to the pie charts as well. Finally, the frequencies of segments coded with personality traits and attitudes were summarized per participant next to the pie charts. This time, I opted for absolute frequencies, since not all segments were coded with traits or attitudes.

4.1.4.5 Flexibility ratio

As discussed in section 2.3, no codes for flexibility will be assigned. Instead, the interaction between segments codes with efficiency and segments coded with innovation was analysed. To give a quantitative indication of flexibility, a ratio between innovation and efficiency was calculated for each participant and presented next to the pie charts. For example, a ratio of 5.00 would mean the participant had five segments coded with efficiency for each segment coded with innovation. The lower the ratio, the more even the balance is between innovation and efficiency. However, Schwartz *et al.* (2005) argue that innovation is mostly complementing efficiency, so a good balance would always be a ratio higher than 1.00 (i.e. more efficiency than innovation). Still, a lower ratio would represent a higher flexibility.

4.1.4.6 Manipulation check

Chi (1997) strongly argues to support the qualitative analysis of the data with quantitative statistical testing to strengthen the validity of any found patterns (step 7 of verbal analysis). Therefore, using the software IBM SPSS Statistics 21, non-parametric tests for independent samples (Mann-Whitney) were done to test for differences in activity codes, segment amounts, completion times and flexibility ratios between the MII and MSS cases, as a check whether both case types were similar.

Also, the differences between participants who were unfamiliar with their case topic prior to the experiment and participants who were familiar with their case topic were tested, as the latter might use a more routine rather than adaptive procedure.

A non-parametric test was chosen because it does not make assumptions about the distribution of the population and is more suitable than a parametric test for small sample sizes (Siegel, 1957). I chose the Mann-Whitney test because it is suitable to data with two independent samples (Siegel, 1957). Of course, due to the very small sample sizes, no strong claims may be derived from these quantitative tests only.

3.2 Results main experiment

Table 3 shows the results of the questionnaire. All participants who expressed dissatisfaction with their solution blamed their lack of information about the subject. All participants but one found that the article lacked applicable information for solving the case. Participants 8 and 11 would normally use different technology, while participant 5 would normally use multidisciplinary discussions. Participants 6, 9, 12 and 13 mentioned they would normally seek information from other disciplines. Participants 5 and 6 mentioned they would normally work on different types of problems.

In Figures 5 to 13, pie charts with relative frequencies of the activity codes are presented per participant, along with case type, the total amount of segments, the completion time of the case, topic familiarity and the calculated flexibility ratio. Absolute frequencies of personality trait codes and attitude codes are presented as well. Additionally, Figure 14 shows box plots for each activity code, showing the distribution of the relative frequencies across all participants. The flexibility ratios ranged from 4.13 to 35.00, with a median of 6.17.

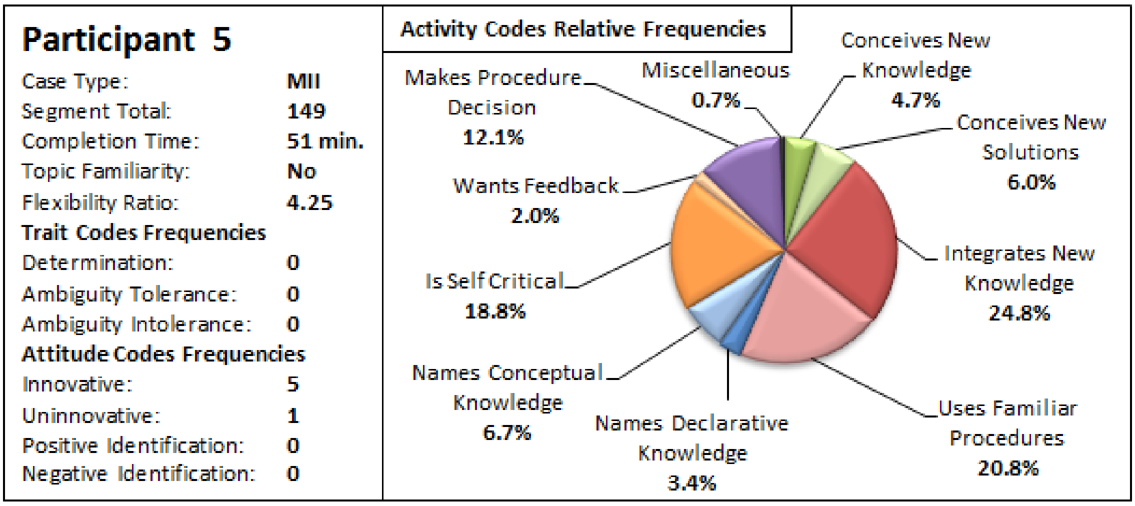


Figure 5. Code Frequencies, Case Type, Length Indicators, Topic Familiarity and Flexibility Ratio of Participant 5

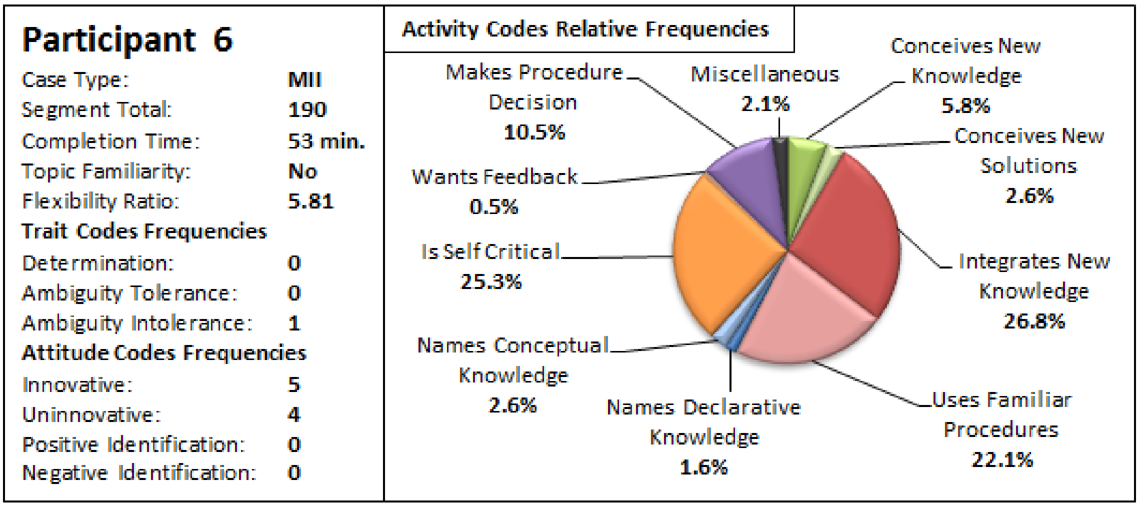


Figure 6. Code Frequencies, Case Type, Length Indicators, Topic Familiarity and Flexibility Ratio of Participant 6

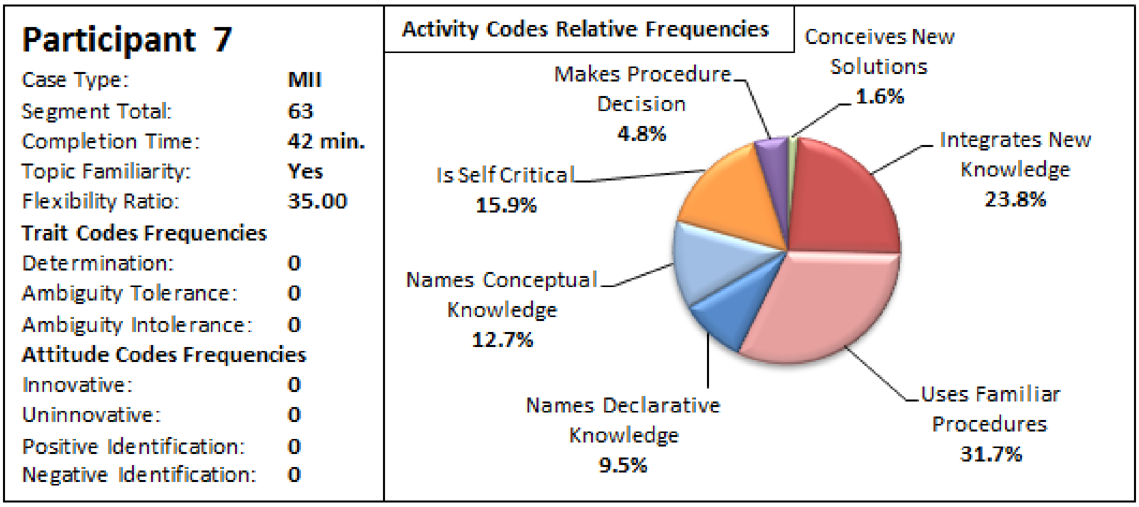


Figure 7. Code Frequencies, Case Type, Length Indicators, Topic Familiarity and Flexibility Ratio of Participant 7

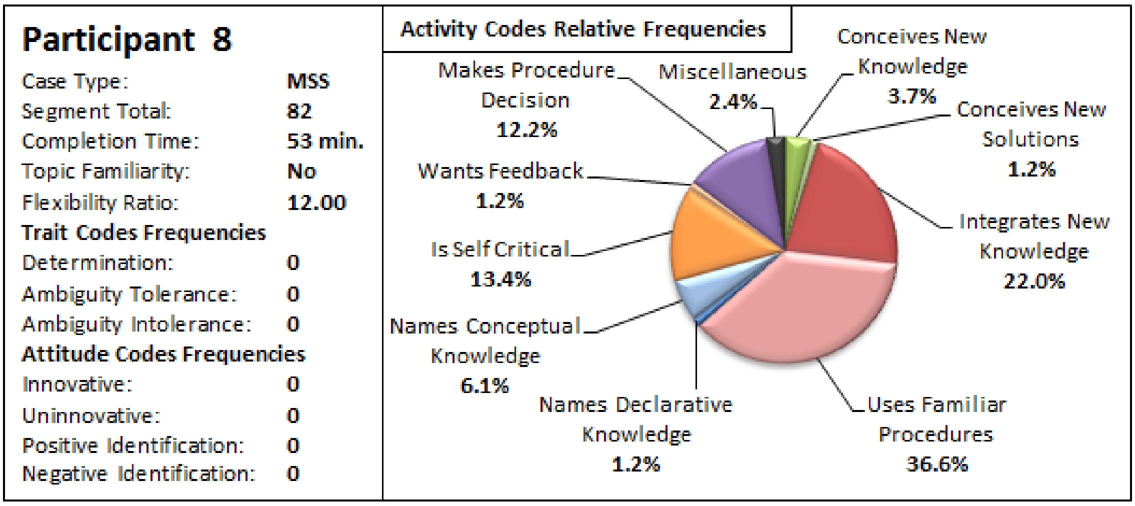


Figure 8. Code Frequencies, Case Type, Length Indicators, Topic Familiarity and Flexibility Ratio of Participant 8

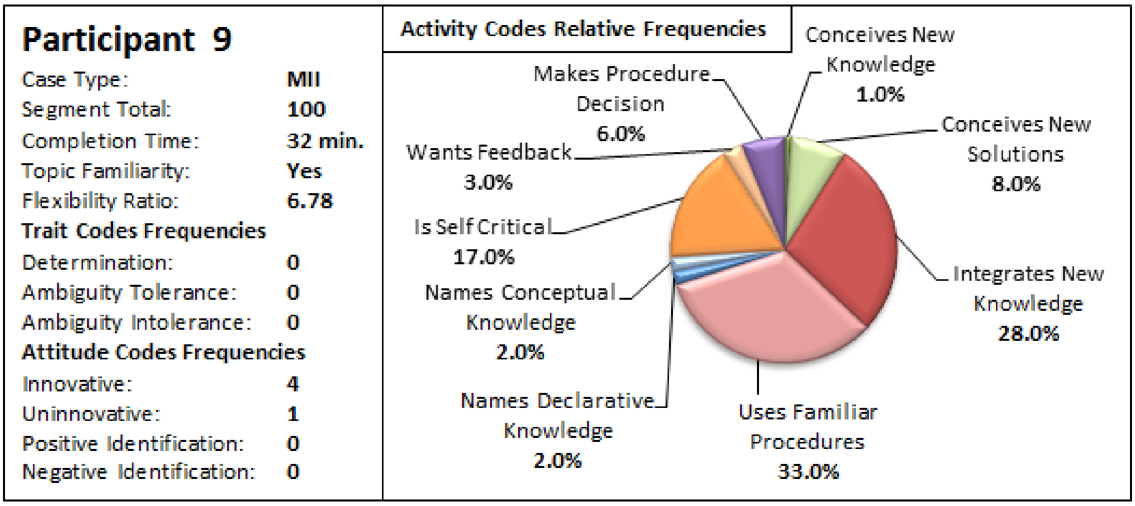


Figure 9. Code Frequencies, Case Type, Length Indicators, Topic Familiarity and Flexibility Ratio of Participant 9

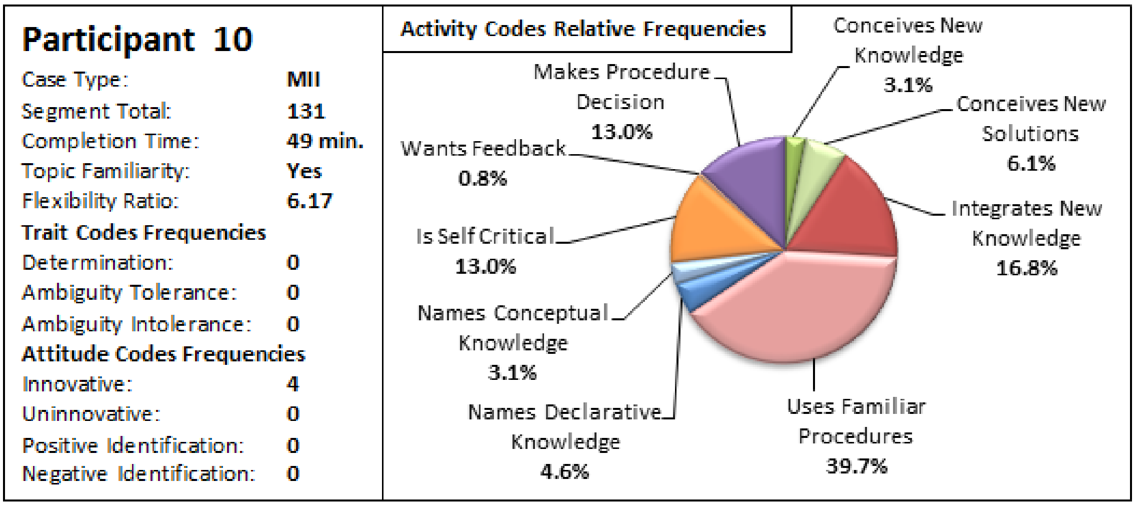


Figure 10. Code Frequencies, Case Type, Length Indicators, Topic Familiarity and Flexibility Ratio of Participant 10

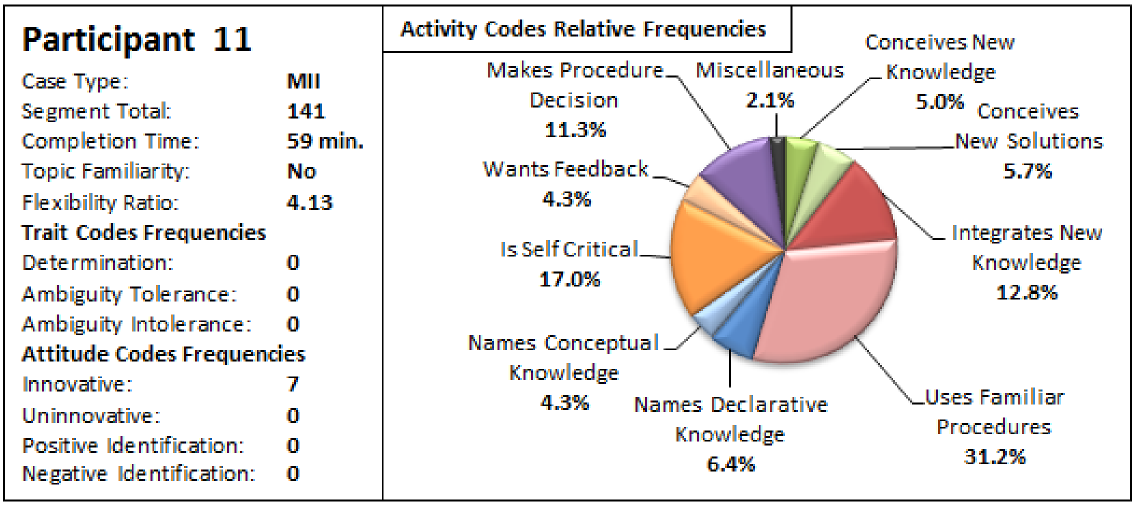


Figure 11. Code Frequencies, Case Type, Length Indicators, Topic Familiarity and Flexibility Ratio of Participant 11

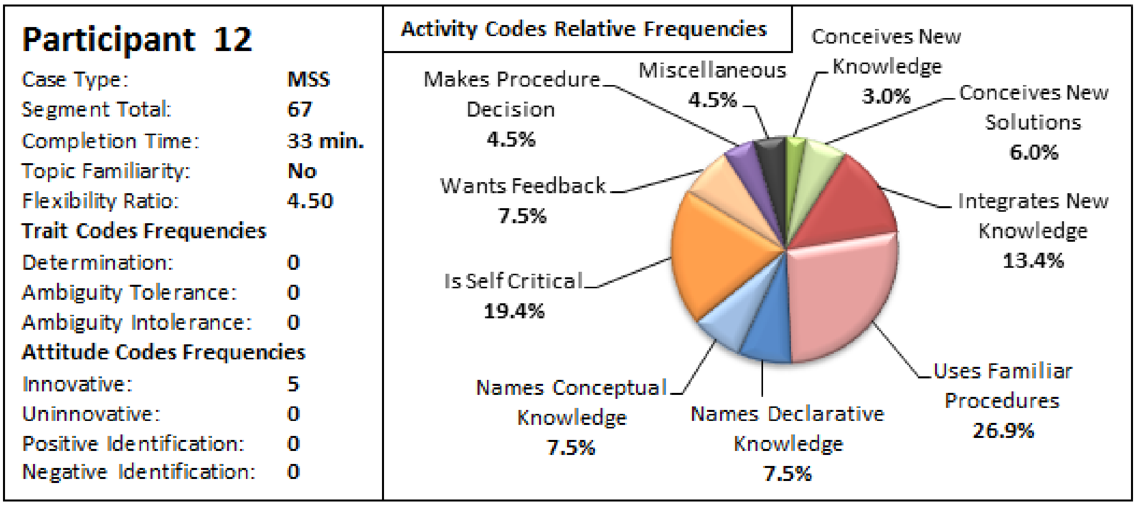


Figure 12. Code Frequencies, Case Type, Length Indicators, Topic Familiarity and Flexibility Ratio of Participant 12

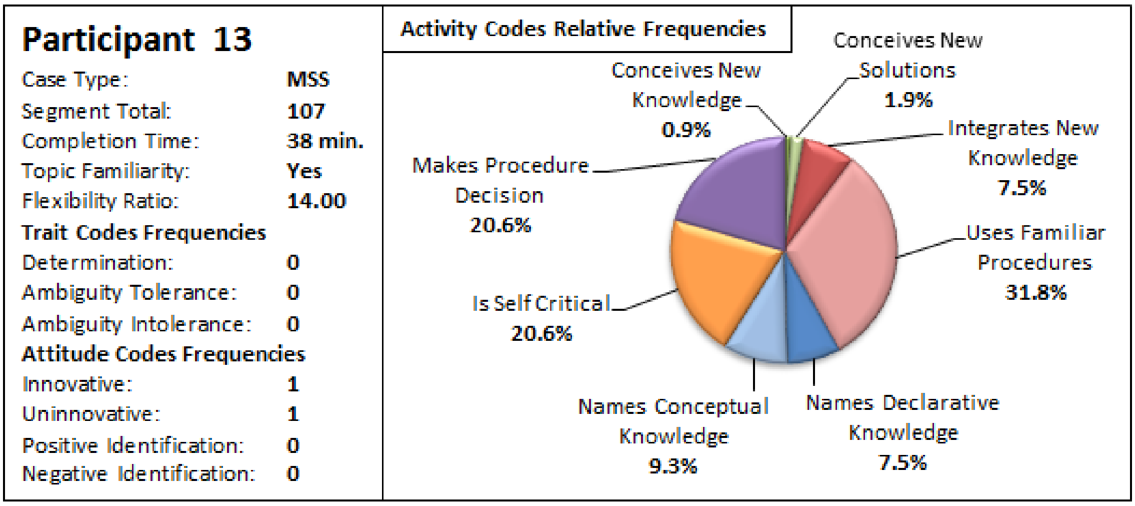


Figure 13. Code Frequencies, Case Type, Length Indicators, Topic Familiarity and Flexibility Ratio of Participant 13

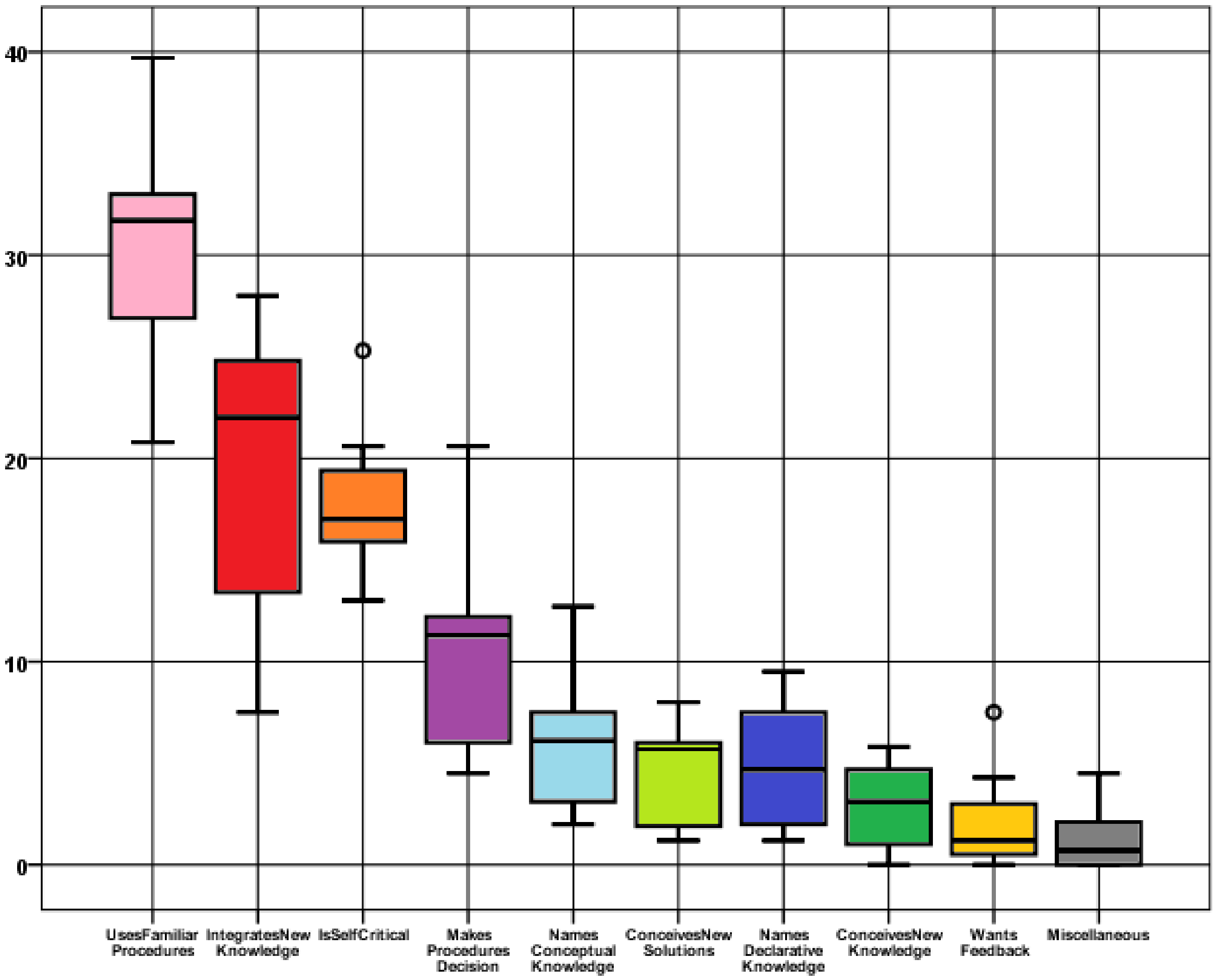


Figure 14. Box Plots of Relative Frequencies per Activity Code across Participants

Table 3. *Participants' Case Types and Questionnaire Results*

Participant	Case type	Case familiarity	Satisfaction	Article Usefulness	Procedure similarity	Work field similarity	Education similarity
5	MII	No	No	No	Small	Small	Large
6	MII	No	No	Yes	Large	Small	Large
7	MII	Yes	Yes	Yes	Large	Very large	Large
8	MSS	No	No	Yes	Small	Large	Large
9	MII	Yes	No	Yes	Large	Large	Very large
10	MII	Yes	Yes	No	Very large	Very large	Large
11	MII	No	Yes	No	Small	Small	Large
12	MSS	No	Yes	No	Large	Very large	Very large
13	MSS	Yes	Yes	No	Large	Large	Large

No significant differences in any of the activity codes or in any of the segment amounts, completion times and flexibility ratios were found between MII cases and MSS cases. Significant differences between participants familiar with their case topic and participants unfamiliar with their topic were only found for ‘Conceives New Knowledge’ codes (Mdn_f = .950, n_f = 4, Mdn_u = 4.70, n_u = 5, Mann-Whitney U = 1.000, p = .032 two-tailed) and ‘Miscellaneous’ codes (Mdn_f = .00, n_f = 4, Mdn_u = 2.10, n_u = 5, Mann-Whitney U = .000, p = .016 two-tailed).

3.3 Discussion main experiment

The goal of the main experiment was to investigate the similarity between problem solving strategies of technical-medical experts and the problem solving strategies that constitute adaptive expertise. To do this, I analysed the verbalizations of TM-graduates who had to solve a technical-medical problem case while thinking aloud. Overall, the results show large proportions of efficiency and metacognition, a moderate amount of decision making and small proportions of innovation and mentioning knowledge, but were indecisive about personality traits and attitudes.

All participants mostly took an efficiency approach, as indicated by the large proportion medians of the codes ‘Integrates New Knowledge’ and ‘Uses Familiar Procedures’. However, there was high variability across all participants, indicated by the large distributions shown in Figure 14. The innovation strategies, ‘Conceives New Knowledge’ and ‘Conceives New Solutions’, were less variable but also much less prevalent than the efficiency strategies. The flexibility ratio median was 6.17, indicating that for each assigned innovation code more than six efficiency codes were assigned.

When examining the data more thoroughly, it becomes clear that while all participants often had groups of multiple consecutive efficiency-coded segments, the innovation-coded segments often only occurred single or in a group of two or three segments. Another striking difference is that while efficiency-coded segments were prevalent throughout the whole session, innovation-coded segments primarily appeared in the middle. This indicates that participants first tried procedures familiar to them before creating new knowledge or solutions, after which they applied these solutions and knowledge to the problem.

One issue was found with efficiency during coding. Some participants were more verbose than others during reading, which influenced the frequencies of the efficiency code ‘Integrates New Knowledge’. For example, participants 6 and 9 verbalized much of what they read out loud, while participant 13 did not read the article at all, which can be clearly seen in the pie charts in Figures 6, 9 and 13. This issue obscures other aspects of this code, such as the usage of information gained from their own innovation.

Metacognition was a very prevalent and consistent proportion across all participants, but primarily because of self-monitoring and ‘fitting’ what they knew about the problems with their prior knowledge (‘Is Self-Critical’) and much less because of the need for feedback (‘Wants Feedback’). Some participants never even mentioned they would like to have feedback. Similar to innovation, the metacognition-coded segments mostly occurred single or in a group of two or three segments, but were prevalent throughout the whole session. This indicates that metacognition strategies were an important part of the problem solving process of the participants.

The prevalence of the codes ‘Names Conceptual Knowledge’ and ‘Names Declarative Knowledge’ was comparable to innovation, and they also occurred mostly single or in a group of two or three segments.

Different to the innovation-coded segments, and similar to the metacognition- and efficiency-coded segments, the knowledge-coded segments were prevalent throughout the whole session. These findings were not surprising, as these codes represent the naming of prior knowledge, after which this knowledge is used through efficiency strategies.

The code ‘Makes Procedure Decision’ was moderately prevalent, but varied highly across participants. However, this code was intended to be a ‘filler’ code in order to reach completeness of the coding scheme and, to my knowledge, the corresponding strategy is not represented by any expert characteristic. Indeed, Carbonell, Stalmijer, Könings, Segers and Van Merriënboer (2014), who recently performed an extensive review on adaptive expertise, mention that goal-setting only shares a very weak correlation with AE (r = .13). Further analysis of this strategy seemed therefore not useful.

The ‘Miscellaneous’ code was only assigned a few times, or even not at all for some participants. This suggests that the coding scheme V4 is fairly complete. However, the large amounts of the codes ‘Is Self-Critical’, ‘Integrates New Knowledge’ and ‘Uses Familiar Procedures’ implicate that metacognition and efficiency could be further divided into more sub-codes for a possible next version of this coding scheme. For example, ‘Integrates New Knowledge’ could be divided into ‘Integrates Article Information’ and ‘Integrates Other Knowledge’. This would also fix the issue that verbosity during reading would obscure other aspects of ‘Integrates New Knowledge’.

A major issue is the fact that based on the current results no conclusions can be drawn about the personality traits and attitudes of the participants. Although only one personality trait and only a few attitudes were found, this is no evidence for the lack of these personality traits and attitudes.

Also, due to different lengths of the transcriptions, the absolute frequencies of these traits and attitudes are not valid measures for the extent of the traits and attitudes. Segments coded with trait and attitude codes are merely indications of the possibility of having these personality traits and attitudes.

Regarding the external validity of the technical-medical cases, the results indicate that the cases were representative of real technical-medical problems, and that both cases were similar to each other. Overall, most participants judged their case as similar to earlier technical-medical problems they encountered, especially those encountered during their Master study. Furthermore, most participants judged their way of working during solving their case as similar to their normal problem solving procedures when dealing with real technical-medical problems. Upon inspection of the data, no patterns were found that might indicate a difference between the MII and MSS cases, although the ‘Miscellaneous’ proportions seemed somewhat higher for MSS than for MII. This lack of difference is supported by the fact that no statistically significant differences were found between both cases.

Since routine experts would show less performance on unfamiliar tasks (De Groot, 1978; Robertson, 2001), while adaptive experts would not (Mylopoulos & Woods, 2009; Mylopoulos & Regehr, 2009; Paletz *et al.*, 2013; Schwartz *et al.*, 2005), the data was further inspected for possible differences between participants familiar and unfamiliar with their case topic.

A few small differences were found. ‘Conceives New Knowledge’ and ‘Miscellaneous’ seemed to have lower proportions for participants familiar than for participants unfamiliar with the topic. The statistically significant differences found between these two groups support this finding. Especially the ‘Miscellaneous’ difference stood out, since all participants familiar with their topic had zero miscellaneous-coded segments.

Furthermore, participants familiar with their topic tended to have lower proportions of 'Wants Feedback' and higher proportions of 'Names Declarative Knowledge'. These differences were not found during statistical testing.

These differences intuitively make sense. When familiar with a topic, one would have more declarative knowledge about this topic and have less need for new knowledge and feedback. However, these differences are small and might very well be found by chance due to the small sample sizes. Based on these findings, no conclusion may therefore be drawn that structural differences exist between experts with varying topic familiarity. At this point, the results suggest a standard way of working of graduated technical physicians for dealing with technical-medical problems, regardless whether these problems are familiar or unfamiliar to them.

Regarding the satisfaction of the participants about their resulting solutions, one could expect that participants who expressed dissatisfaction due to a lack of information would be more likely to judge the review article as 'not useful'. Furthermore, being unfamiliar with the case topic could very well lead to dissatisfaction when the information was found lacking. However, no patterns could be identified from these variables. The same is true for the solution types and levels of detail; I was not able to identify any patterns with any of the other variables.

4. General discussion

Technical-medical expertise is a relative new domain of expertise, born from the need for professionals who are skilled in both medical and technological domains in the Netherlands (IGZ, 2008). I argued that the TME of these technical physicians is similar to adaptive expertise, but this remained to be tested.

Also, it was not known how the flexible and innovative nature of technical-medical expertise manifests itself in problem solving strategies (operationalized as the activities during solving problems that reflect expertise characteristics). The goal of my research was to fill this knowledge gap. More specifically, the research question was: 'To what extent are problem solving strategies of technical-medical experts similar to the problem solving strategies that constitute adaptive expertise?'

Overall, I can conclude that the problem solving strategies of technical-medical experts are at least superficially similar to the problem solving strategies that constitute adaptive expertise, but that more research is needed to investigate the structural similarities. More specifically, while all AE characteristics that have directly underlying problem solving strategies (i.e. metacognition, conceptual knowledge, efficiency, innovation and flexibility) seem to be characteristics of TME as well, it is currently not known in which proportions these characteristics are represented in RE and in AE. This makes it hard to conclude whether TME, as shown by the participants, is structurally more similar to AE or to RE. Furthermore, the fact that no conclusions could be drawn about the personality traits and attitudes of the participants is a major complication for determining whether technical physicians can be considered adaptive experts, as these traits and attitudes are part of what constitutes AE (Brophy *et al*., 2004; Fisher & Peterson, 2004; Mylopoulos & Regehr, 2009; Mylopoulos & Woods, 2009), as shown in Figure 3.

As discussed in section 3.3, participants mostly used efficiency strategies and much less innovation strategies. This seems contradictory with the fact that efficiency was considered to be a weakly defining characteristic of AE (see Figure 3) and innovation to be a strongly defining characteristic. However, the current results do not provide counterevidence against this.

That is because it may very well be true that adaptive experts use (almost) as much efficiency strategies as routine experts do, complemented by a small amount of innovation strategies. The innovativeness of adaptive experts would then be more about the impact of innovation strategies rather than the amount of strategies. Again, more research is needed on the strategy proportions of both AE and RE.

The same need for more research holds for metacognition and conceptual knowledge. While it was argued that adaptive experts, compared to routine experts, have higher metacognition (Fisher & Peterson, 2001; Hatano & Inagaki, 1984; Robertson, 2001) and higher conceptual knowledge (Hatano & Inagaki, 1984; Paletz *et al.*, 2013), it cannot be concluded from the current results whether metacognition and conceptual knowledge is used in a similar amount in TME as in AE or in RE.

A related point can be made for flexibility, which was measured using a flexibility ratio. This ratio was the amount of innovation-coded segments relative to efficiency-coded segments, and could be used as a measure for flexibility (or adaptability), since according to Schwartz *et al.* (2005) adaptive experts are able to balance efficiency and innovation by working in an 'optimal adaptability corridor'. Note, however, that while I argued that a higher ratio means less flexibility/adaptability, it is not known which flexibility ratio represents this optimal adaptability corridor. More important even, Schwartz *et al.* (2005) do not go into detail about what this optimal adaptability corridor looks like, or in other words, how efficiency and innovation are being balanced. This is also not explicated in the literature review on AE by Carbonell *et al.* (2014). This lack of knowledge about the nature of flexibility is definitely something that is in need for more research.

One interesting result was that segments coded with declarative knowledge are almost equally represented in the results as segments coded with conceptual knowledge. This naturally leads to the question whether declarative knowledge might also be important to AE.

As it turns out, it is: declarative knowledge does indeed have some impact on AE (Carbonell *et al.*, 2014). More importantly, adaptive and routine experts share the same *extent* of domain knowledge, while differing in knowledge representation (Carbonell *et al.*, 2014). This implies that information about the extent of declarative and conceptual knowledge will not be enough to reliably compare TME to AE and RE, but that instead knowledge representations need to be investigated.

Apart from the fact that my research failed to investigate the knowledge representations of technical physicians, my methodology had a few more limitations that I would like to summarize here. First, the value of statistical tests was low due to the very small sample sizes. Second, due to time restraints the analysis procedure was not carried out twice, as is advocated by Chi (1997). Third, the coding scheme only had moderate inter-coder reliability (Landis & Koch, 1977; Someren *et al.*, 1994). Fourth, no discussions with a colleague or supervisor about the main data and results were performed after testing the coding scheme to reduce the subjectivity of the qualitative analysis (Chi, 1997). And finally, the questionnaire should have been extended with items that measure the personality traits and attitudes shown in Figure 3, instead of trying to assign codes to segments by chance.

Possible follow-up studies to my research should definitely focus on the following three questions. First: what are the problem solving strategy proportions of adaptive and routine experts? By studying this, a better comparison can be made between TME, or rather domains in which healthcare and technology interact, and AE or RE. This way, a conclusion may be drawn whether TME is structurally similar to AE or not. Second: what is the nature of flexibility and the optimal adaptability corridor? The lack of knowledge about this subject is a major complication for determining whether TME, or rather any type of expertise, can be classified as adaptive. The flexibility ratio might be a useful measure to start investigating with.

And third: which attitudes and personality traits do technical physicians have? By answering this question, technical physicians can be more structurally compared to adaptive experts.

Overall, this exploratory research provided the first basic evidence for the nature of technical-medical expertise, and its similarity to adaptive expertise. I would like to emphasize 'basic' here, as there are still many questions left unanswered, such as those regarding the true expert characteristic proportions of adaptive and routine expertise, the personality and attitudes of technical physicians and the optimal balance between efficiency and innovation. I can only hope that this research will inspire others to pick up where I have left, as knowledge in this domain will ultimately help to improve medical education, technology and healthcare.

Acknowledgements

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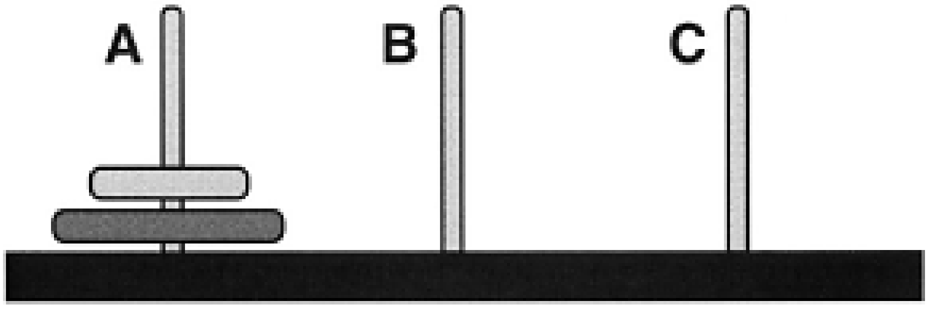
Appendix I: Practice problem

Oefening. Dit is een oefening om u te laten wennen aan het hardop nadenken tijdens het oplossen van een probleem. Deze oefening zal niet worden meegenomen in de resultaten van het onderzoek.



Bron: Robertson, S. I. (2001). *Problem Solving.* 27 Church Road, Hove, East Sussex: Psychology Press

Opdracht. Uw opdracht is als volgt: beschrijf *hardop nadenkend* hoe u beide ringen in *drie stappen* van pin A naar pin C zou brengen, waarbij de volgende regels van kracht zijn:

- U kunt slechts *één* ring tegelijkertijd van de ene pin naar de andere pin verplaatsen.
- U kunt de grote ring *niet* bovenop de kleine ring plaatsen.

Appendix II: MII technical-medical problem case

Casus. Voor de diagnostiek van prostaatkanker bestaan op dit moment verschillende methodes, ieder met hun eigen belemmeringen voor goede diagnostiek. Eén van deze methodes is de *'transrectal ultrasound (TRUS) guided biopsy'*, dat wordt gezien als de huidige gouden standaard voor de diagnose van prostaatkanker. Deze methode heeft echter eveneens belemmeringen. Het gebied van de prostaat dat bereikbaar is met een naald is *beperkt*, en de prostaat kan tijdens de procedure *bewegen of vervormen* als gevolg van handbewegingen van de arts.

Opdracht. Uw opdracht is als volgt: bedenk en beschrijf een concept waarbij de belemmeringen van 'TRUS guided biopsy' voor de diagnose van prostaatkanker worden opgelost.

Procedure. *Denk hardop na* gedurende het bedenken, uitwerken en beschrijven van het concept. Dat wil zeggen, benoem al uw gedachten, overwegingen, ideeën en stappen hardop op het moment dat deze plaatsvinden. Probeer zo duidelijk mogelijk te praten.
Schrijf de *uiteindelijke* beschrijving van het concept hieronder op. U mag uw beschrijving eventueel ondersteunen met behulp van ondersteunende schetsen, zolang uw beschrijving *volledig* blijft. U heeft *maximaal* 60 minuten de tijd. De onderzoeker zal u na 30, 45 en 55 minuten herinneren aan de tijd.

Beschrijving. ………………………………………………………………………………………

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Appendix III: MSS technical-medical problem case

Casus. In het verleden dacht men dat bij kunstmatige beademing alleen een hoge *beademingsdruk* schadelijk was voor de long. Tegenwoordig is bekend dat óók een groot *teugvolume* en het optreden van (micro) *atelectase* door onvoldoende ‘positive end-expiratory pressure’ (PEEP) tot schade kunnen leiden. De ontstekingsreactie die hierdoor ontstaat in de long blijft waarschijnlijk niet tot de long beperkt, maar kan zich over het hele lichaam uitbreiden. Een minder optimaal ingestelde beademing kan dus leiden tot het optreden van multipel orgaan falen en het overlijden van de patiënt.

Opdracht. Uw opdracht is als volgt: bedenk en beschrijf een concept waarbij de schadelijke *mechanismen* van kunstmatige beademing *bewaakt* kunnen worden en die het tevens mogelijk maakt om voor de individuele patiënt de *ideale instelling* te vinden.

Procedure. *Denk hardop na* gedurende het bedenken, uitwerken en beschrijven van het concept. Dat wil zeggen, benoem al uw gedachten, overwegingen, ideeën en stappen hardop op het moment dat deze plaatsvinden. Probeer zo duidelijk mogelijk te praten.
Schrijf de *uiteindelijke* beschrijving van het concept hieronder op. U mag uw beschrijving eventueel ondersteunen met behulp van ondersteunende schetsen, zolang uw beschrijving *volledig* blijft. U heeft *maximaal* 60 minuten de tijd. De onderzoeker zal u na 30, 45 en 55 minuten herinneren aan de tijd.

Beschrijving. ……………………………………………………………………………………

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Appendix IV: Questionnaire

Bedankt voor het uitwerken van de casus! Tot slot volgen nog enkele vragen.

1. **Wanneer bent u afgestudeerd voor uw master Technical Medicine?**

   ……………………………………………………………………………………………….

2. **Was u voorafgaand aan dit onderzoek al bekend met het onderwerp van de casus? Zo ja, waarvan?**

   □ Ja, namelijk van ……………………………………………………………………

   ……………………………………………………………………………………...

   ……………………………………………………………………………………...

   □ Nee.

3. **Hoe groot is de overeenkomst tussen uw werkwijze bij deze casus en uw werkwijze die u normaal gesproken toepast op Technisch Geneeskundige problemen? Licht uw antwoord eventueel toe.**

   □ Heel grote overeenkomst.
   □ Grote overeenkomst.
   □ Kleine overeenkomst.
   □ Heel kleine overeenkomst.

   Eventuele toelichting:

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4. **Hoe groot is de overeenkomst tussen deze casus en problemen die u tegenkomt in uw huidige werkveld? Licht uw antwoord eventueel toe.**

- □ Heel grote overeenkomst.
- □ Grote overeenkomst.
- □ Kleine overeenkomst.
- □ Heel kleine overeenkomst.

Eventuele toelichting:

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5. **Hoe groot is de overeenkomst tussen deze casus en problemen die u bent tegengekomen tijdens de opleiding Technische Geneeskunde? Licht uw antwoord eventueel toe.**

- □ Heel grote overeenkomst.
- □ Grote overeenkomst.
- □ Kleine overeenkomst.
- □ Heel kleine overeenkomst.

Eventuele toelichting:

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6. **Vond u het wetenschappelijke artikel nuttig voor het uitwerken van de casus? Licht uw antwoord eventueel toe.**

   ◻ Ja.
   ◻ Nee.

   Eventuele toelichting:

   ……………………………………………………………………………………………

   ……………………………………………………………………………………………

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7. **Bent u tevreden met uw resultaat van de casus? Licht uw antwoord eventueel toe.**

   ◻ Ja.
   ◻ Nee.

   Eventuele toelichting:

   ……………………………………………………………………………………………

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Dit waren de vragen. Hartelijk dank voor het invullen van deze vragenlijst, en natuurlijk voor uw deelname aan dit onderzoek! Uiteraard worden al uw individuele resultaten op vertrouwelijke wijze behandeld. Als u geïnteresseerd bent in de resultaten van dit onderzoek, vul dan hieronder uw e-mailadres in. Zodra het onderzoek afgerond is, zullen de resultaten naar u toegestuurd worden.

E-mailadres: ……………………………………………………………………………...

Appendix V: Coding scheme V4

N.B.: alle tekst tussen […] hoeft niet gesegmenteerd (of gecodeerd) te worden, aangezien deze alleen dienen voor context!

Stap 1: Coderen van irrelevante informatie.

Codeer alles wat niet te maken heeft met het oplossen van het probleem met '**NON-CONTENT**'. Kleur de bijbehorende tekst rood.

Voorbeelden**:**
- *Vragen* over de onderzoeksprocedure (bijv. "waar moet ik de oplossing opschrijven?").
- **LET OP**: opmerkingen zoals "nu ga ik lezen" of "ik pak mijn pen" vallen niet onder deze categorie, aangezien deze iets zeggen over *beslissingen* van de deelnemer.
- Afsluitende opmerkingen (bijv. "ik ben klaar").
- Het (hardop) beschrijven van de oplossing op het antwoordformulier.
- Reacties van de deelnemer op prompts.

Stap 2: Segmenteren van de relevante informatie.

Verdeel de relevante (dus niet gekleurde) tekst in *segmenten*. Een segment bestaat uit een zinsdeel, een zin, zinsdelen of zinnen die samen één onderwerp vormt of vormen. Segmenten vlak *voor* en vlak *na* segment X beschrijven dus een *ander* onderwerp dan segment X. Controleer dit door het segment (in je hoofd) een korte, beschrijvende titel te geven op basis van de *inhoud* van het onderwerp (dus niet op basis van waarin het onderwerp *ingedeeld* zou kunnen worden), en je af te vragen of alles binnen het segment onder die titel valt.

Stap 3: Doornemen achtergrond deelnemer.

Neem voorafgaand aan het coderen de achtergrondinformatie van de deelnemer door. Kijk hiervoor allereerst naar diens afgeronde *Masterspecialisatie*. Kijk vervolgens in de resultaten van de vragenlijst naar diens *bekendheid* met het onderwerp, *overeenkomst* van de casus met werkveld en opleiding, en de eventuele *toelichtingen* van de deelnemer hierop.

Stap 4: Codering van de relevante informatie.

Wijs één of meerdere *codes* toe aan ieder segment. Doorloop hiervoor de volgende stappen:
1. Wijs aan alle segmenten één code uit Codelijst 1 (activiteiten) toe. *Alle* segmenten worden in deze stap dus gecodeerd.
2. Wijs aan alle segmenten die binnen Codelijst 2 vallen één code uit Codelijst 2 (persoonlijkheid) toe. Alleen de hier *relevante* segmenten worden in deze stap dus gecodeerd.
3. Wijs aan alle segmenten die binnen Codelijst 3 vallen één code uit Codelijst 3 (attitude) toe. Alleen de hier *relevante* segmenten worden in deze stap dus gecodeerd.

In *iedere* stap wordt dus de *volledige* transcriptie geanalyseerd.

Codelijst 1: Activiteiten.

(Innovatie)

- **ConceivesNewKnowledge**: als de deelnemer op basis van het artikel en/of eigen ervaring kennis/ideeën (in het algemeen) bedenkt die op dat moment voor hem *nieuw* is.
  Bijvoorbeeld: "Als dat zo is, dan is het waarschijnlijk dat het in dit geval zó werkt!"
- **ConceivesNewSolutions**: als de deelnemer één of meerdere oplossingen voor het probleem bedenkt die hij niet letterlijk uit het artikel gehaald heeft en op dat moment voor hem nieuw is.
  Bijvoorbeeld: "Wat misschien ook kan, is om het probleem zó aan te pakken!"

LET OP: bij twijfel tussen deze twee codes, kies de code 'ConceivesNew*Knowledge*'!

(Efficiëntie)

- **IntegratesNewKnowledge**: als de deelnemer tijdens onderzoek verkregen (m.b.v. artikel) of eerder in het onderzoek bedachte kennis/informatie onderbrengt in zijn eigen kennis. **LET OP**: alle segmenten waarin wordt gerefereerd naar de *probleembeschrijving/casus* vallen niet binnen deze categorie!
  Voorbeelden:
  - Hij formuleert tijdens onderzoek verkregen of bedachte informatie in eigen woorden.
    Bijvoorbeeld: "Dit is dus eigenlijk een standaard techniek voor beeldvorming."
  - Hij combineert tijdens onderzoek verkregen of bedachte informatie met eerdere informatie of kennis.
    Bijvoorbeeld: "Waarschijnlijk dat voor deze techniek drie artsen nodig zullen zijn."
  - Hij geeft kritisch commentaar op het artikel.
    Bijvoorbeeld: "De methode van deze auteurs laat te wensen over."
  - Hij leest hardop informatie voor uit het artikel.
- **UsesFamiliarProcedures**: als uit het segment blijkt dat de deelnemer een voor hem bekende werkwijze hanteert. **LET OP**: alle segmenten waarin wordt gerefereerd naar het *artikel* vallen niet binnen deze categorie!
  Voorbeelden:
  - Probleemanalyse: hij analyseert waaruit het probleem *bestaat*.
    Bijvoorbeeld: "Even kijken, het probleem is dus…"
  - Hij bepaalt de anatomie, (patho)fysiologie en technologie van het probleem.
  - Hij benoemt/geeft een samenvatting van eerder benoemde (uiteindelijke of gedeeltelijke) oplossing(en).
  - Evaluatie: hij bepaalt of de (uiteindelijke of gedeeltelijke) oplossing(en) *goed genoeg* is/zijn om het probleem op te lossen.
    Bijvoorbeeld: "Is mijn concept zo volledig?"

(Benoemen van kennis)

- **NamesDeclarativeKnowledge**: als de deelnemer *feitenkennis* benoemt, niet gebruikt(!), die hij al bezat *voorafgaand* aan het onderzoek.
  Bijvoorbeeld: "Prostaatkanker komt alleen bij mannen voor."

- **NamesConceptualKnowledge**: als de deelnemer kennis benoemt, <u>niet</u> gebruikt(!), die hij al bezat *voorafgaand* aan het onderzoek, en die iets zegt over *hoe* iets werkt en *waarom* het zo werkt.
  Bijvoorbeeld: “Bij een tumor kan je asymmetrie in de prostaat verwachten.”

LET OP: indien er overlap is tussen een ‘Names(…)Knowledge’-code en een Innovatie- of Efficiëntie-code, kies dan de Innovatie- of Efficiëntie-code!

(Metacognitie)

- **IsSelfCritical**: als de deelnemer één of meerdere van onderstaande zaken laat blijken.
  - Hij denkt (kritisch) na over zijn eigen *aannames* en/of *ideeën* (of deze *kloppen* of niet).
    Bijvoorbeeld: “Is dat nu wel waar wat ik nu zeg?”
  - Hij denkt (kritisch) na over zijn eigen *begrip* van het probleem. **LET OP**: nadenken over waaruit het probleem *bestaat*, is onderdeel van ‘UsesFamiliarProcedures’ (tijdens probleemanalyse).
    Bijvoorbeeld: “Weet ik nu genoeg om een goed concept te kunnen beschrijven?”
  - Hij denkt (kritisch) na tot in hoeverre het onderwerp binnen zijn *expertise* valt.
    Bijvoorbeeld: “Is dit iets wat ik überhaupt op kán lossen?”
- **WantsFeedback**: als de deelnemer laat blijken dat hij in contact zou willen treden met mensen voor overleg, informatie en/of feedback, of als de deelnemer laat blijken dat hij meer informatie zou willen hebben en/of zoeken. **LET OP**: opmerkingen zoals “nu ga ik het artikel lezen” vallen hier niet onder, omdat die gaan om beslissingen over de informatie die de deelnemer al *wel* heeft (‘MakesProcedureDecision’).
  Bijvoorbeeld: “Nu zou ik eigenlijk met de arts willen overleggen over mijn concept.”

(Beslissingen)

- **MakesProcedureDecision**: als de deelnemer een besluit neemt over de te volgen *werkwijze*. Voorbeelden:
  - Hij besluit welk probleem hij aanpakt. **LET OP**: dit is <u>niet</u> de probleemanalyse, maar een *keuze* tussen de problemen die al geïdentificeerd *zijn* (tijdens probleemanalyse).
    Bijvoorbeeld: “Eerst maar eens naar de vervorming van de prostaat kijken.”
  - Hij besluit welke oplossing hij gaat uitwerken. **LET OP**: dit is <u>niet</u> het *bedenken* van oplossingen, maar een *keuze* tussen oplossingen die bedacht *zijn* (tijdens innovatie).
    Bijvoorbeeld: “Ik ga voor de oplossing met MRI.”
  - Hij besluit *hoe* hij een oplossing wil gaan uitwerken.
    Bijvoorbeeld: “Ik ga luchtwegen tekenen en daar een beschrijving van geven.”
  - Hij besluit wat zijn volgende activiteit wordt. **LET OP**: dit is dus <u>niet</u> de activiteit zelf, maar het *besluit* om die activiteit te gaan uitvoeren.
    Bijvoorbeeld: “Nu ga ik lezen.” of “Nog even een keer naar mijn oplossing kijken.”

(Overig)

- **Miscellaneous**: als geen van bovenstaande codes zijn toe te wijzen aan het segment.

Codelijst 2: Persoonlijkheid.

- **Trait-Determination**: als in het segment de deelnemer laat blijken dat hij *vastbesloten* is de oplossing voor het probleem te vinden én in *eerdere* segmenten (of hetzelfde segment) heeft laten blijken dat hij het *lastig* vindt om die oplossing te vinden.
Bijvoorbeeld: "Dit vind ik erg lastig, maar het gaat me lukken!"
- **Trait-AmbiguityTolerance**: als de deelnemer laat blijken dat hij het *niet* erg vindt om met ambigue informatie te werken. **LET OP**: het gaat hier om *ambigue* informatie (onduidelijk en/of lastig te interpreteren) en niet om een *gebrek* aan informatie!
Bijvoorbeeld: "Deze informatie is onduidelijk, maar dat is niet zo'n probleem."
- **Trait-AmbiguityIntolerance**: als de deelnemer laat blijken dat hij het *wel* erg vindt om met ambigue informatie te werken. **LET OP**: het gaat hier om *ambigue* informatie (onduidelijk en/of lastig te interpreteren) en niet om een *gebrek* aan informatie!
Bijvoorbeeld: "Ik kan niets met deze onduidelijke informatie!"

Codelijst 3: Attitudes.

- **Attitude-PositiveDomainIdentification**: als de deelnemer laat blijken dat hij *positief* staat tegenover zijn rol binnen Technische Geneeskunde en/of zijn rol als Technisch Geneeskundige.
Bijvoorbeeld: "Ik ben blij dat ik Technische Geneeskunde heb gestudeerd."
- **Attitude-NegativeDomainIdentification**: als de deelnemer laat blijken dat hij *negatief* staat tegenover zijn rol binnen Technische Geneeskunde en/of zijn rol als Technisch Geneeskundige.
Bijvoorbeeld: "Misschien was traditionele geneeskunde voor mij beter geweest."
- **Attitude-Innovative**: als de deelnemer één of meerdere van onderstaande zaken laat blijken.
  - Hij staat open voor, of heeft behoefte aan, nieuwe informatie/feedback.
  Bijvoorbeeld: "Mogelijk kan deze informatie helpen." of "Even het artikel lezen."
  - Hij ziet problemen als een mogelijkheid om te kunnen groeien of kennis te vergroten.
  Bijvoorbeeld: "Zonder problemen kom je ook niet verder!"
  - Hij vindt dat problemen op meerdere manieren zijn op te lossen.
  Bijvoorbeeld: "Dit probleem valt natuurlijk op verschillende wijzen aan te pakken."
- **Attitude-Uninnovative**: als de deelnemer één of meerdere van onderstaande zaken laat blijken.
  - Hij staat *niet* open voor, of heeft *geen* behoefte aan, nieuwe informatie/feedback.
  Bijvoorbeeld: "Ik denk niet dat meer informatie erg nuttig is." of "Het artikel heb ik niet nodig."
  - Hij ziet problemen als nutteloze obstakels.
  Bijvoorbeeld: "Het beste is om helemaal geen problemen te hebben."
  - Hij vindt dat een probleem op slechts één manier is op te lossen.
  Bijvoorbeeld: "Er kan slechts één goede aanpak zijn."