Knowledge Representation and Adaptive Expertise

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Abstract

The concept of adaptive expertise seems promising in enriching educational programs and helping students to apply their knowledge to different fields. However, the concept is not well understood, yet. This study attempts to investigate whether abstract knowledge representation is an aspect of adaptive expertise by conducting a card sorting study. The card sorting of two study programs, technical medicine and medicine, were compared in two cases, prostate cancer and tungiasis. The main quantitative results show that technical medicine students show more abstractive knowledge. The explanatory power of this study is limited to students, rather than true experts. Additionally, the explanatory power of the quantitative results is difficult to estimate, since it is not possible to determine whether differences result from perspectives of the two groups. In conclusion, this study indicates that further research of the role of abstract knowledge representation in adaptive expertise is promising. Future studies should investigate individual differences instead of group comparisons.

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1 INTRODUCTION

The development and implementation of technology in medicine is faster than ever. Technological advancements that needed centuries before are nowadays implemented within a much shorter timeframe (Kramme, & Kramme, 2007). The interaction between medicine and technology confronts medical professionals/physicians with a rapidly changing working environment. Medical professionals not only need to be well- informed about the medical field but also have to learn to use the ever changing technology in healthcare. A study by Deloitte emphasises this point: Their study asked Hospital CEO’s what skills medical professional of the future must hold. One demand is the medical professional’s ability to be innovative (Greenspun, Abrams, & Kane,). All in all it can be stated that medical professionals are faced with ever changing contexts and as a result need the ability to navigate through a multitude of challenges throughout their working life. The ability to apply knowledge to new situations and to grow as a professional when faced with unfamiliar challenges should be a fundamental part of their professional training. Logically, it is the task of the educational sector to prepare students beyond a particular domain expertise and enable them to continuously learn and adapt to changing challenges (Unger, Rauch, Frese, & Rosenbusch, 2011; Nelson & Phelps, 1966; Heunks, 1998). Currently medical curricula are criticised for their emphasis on learning facts rather than on learning to learn (Cooke, Irby and O'Brien, 2010).

An answer to the need to be able to excel in performance in unfamiliar situations is the concept of adaptive expertise coined by Hatano & Inagaki (1986) (e.g. Bohle Carbonell, Stalmeijer, Könings, Segers, & van Merriënboer, 2014). While adaptive expertise has become an elementary part of educative programs (e.g. Wetzel, De Arment, & Reed,

2015) it still needs to be identified how adaptive expertise develops and which aspects constitute it (Chi, 2011). The point is that adaptive expertise is still in its infancy and needs to be evaluated and understood in order to become an effective tool in education.

1.1 THE CONCEPT OF ADAPTIVE EXPERTISE

1.1.1 Expertise in general

In the following section the concept of adaptive expertise is introduced. Before turning to the concept itself, expertise research in general is introduced.

The rapid application of knowledge is at the heart of expertise research: Originating from the study of chess masters, expertise has been associated with the capacity to quickly identify meaningful patterns and apply domain knowledge to a specific domain of expertise (Chase, & Simon, 1973; Chi & Glaser, 1988; Cross, 2004). In addition, experts have also shown superior performance in the context of unfamiliar problems due to their capacity to apply procedural knowledge (Schraagen, 1993). However, expertise has also been associated with cognitive entrenchment or the application of domain knowledge when it does not fit (Dane, 2010, Wiley, 1998). In summary, the application of knowledge to problem cases has been a crucial aspect of expertise.

1.1.2 Adaptive expertise

In contrast to the expertise described above, Hatano & Inagaki (1986) have conceptualised adaptive expertise. Originally, Hatano & Inagaki (1986) have distinguished between adaptive expertise and routine expertise. Routine expertise refers to individuals who are capable to outperform others in familiar situations while adaptive experts outperform others in changing challenges. Accordingly, adaptive expertise is defined as expertise in the context of change or the excelling performance of individuals in changing conditions (Bohle Carbonell, Stalmeijer, Könings, Segers, & van Merriënboer, 2014).

1.1.3 Conceptualisations of AE

In addition to the general definition of adaptive expertise, several conceptualisations of the relationship between routine/general expertise and adaptive expertise have been proposed.

While Hatano & Inagaki have distinguished between routine expertise and adaptive expertise, some more recent authors propose a bridge between routine/general expertise and adaptive expertise. Chi (2011) for instance links adaptive expertise to continuous learning efforts (Chi, 2011; Brophy, Hodge, & Bransford, 2004). To be more precise, Chi (2011) argues that similarities exist between experts engaging in deliberate practice, also described as elite experts, and adaptive expertise. According to Chi (2011) both expert groups possess a good understanding of processes in their own field of expertise and are able to reassess their decision behaviour in a particular case. On that account, adaptive experts as well as elite experts are able to apply their knowledge to understand unfamiliar topics (Chi, 2011). In comparison to Hatano & Inagaki (1986), Chi (2011) links routine and adaptive expertise and thereby implies that adaptive expertise is to some extent an extension of routine expertise. Similar to this conceptualisation, Paletz, et al. (2013) summarise adaptive expertise to encompass more than just creativity and innovation coupled with routine expertise, but additionally a framework for developing such expertise.

Furthermore, a frequently-used distinction is offered by Schwartz, Bransford and Sears (2005) who conceptualise adaptive expertise as a trade-off between innovation and efficiency. In this conceptualisation routine expertise is characterised by the optimised efficiency, quickly identifying domain-specific solutions to defined problems. At the other end of the continuum are novices, who provide creative solutions but lack domain knowledge. Adaptive expertise is the balance between both, applying domain knowledge while considering alternatives. Whereas routine expertise involves learning to quickly apply domain-specific strategies to a particular task, adaptive expertise is associated with the capacity to identify when certain strategies are applicable or not (Koszlowski, 1998; as cited in Paletz, Kim, Schunn, Tollinger, & Vera, 2013).

Despite differences in the relationship between routine expertise and adaptive expertise, all of the above-mentioned conceptualisations share the assumption that adaptive expertise can be achieved through learning experiences.

Adaptive expertise has frequently been used in the context of teaching. For instance, adaptive expertise is used as a theoretical concept to guide expertise development (e.g. Wetzel, De Arment, & Reed, 2015; Verschaffel, Luwel, Torbeyns, & Van Dooren, 2007). Hence, Wetzel, De Arment and Reed (2015) assumed that an individual's reflection of his/her practices leads to adaptive expertise. To proof their assumption, they set up a study in which the reflection of teachers was promoted. When teachers were deliberate about their actions they showed the capacity to react differently to different children (Wetzel, De Arment and Reed, 2015).

An additional link has been made between adaptive expertise and meta-cognitive capabilities and flexibility (Crawford, Schlager, Toyama, Riel, & Vahey, 2005; Griffin & Hesketh, 2003; Bohle Carbonell, et al., 2014). For instance, experiences of change have been correlated with adaptive performance, such as the opportunity to make experiences across different settings and contexts (Pulakos, et al., 2002; Han, & Williams, 2008). Adaptive expertise has been related to routine expertise, individual skills and personal experiences. However, the reported relations between adaptive expertise and these sub-skills are often not very strong and it remains necessary to find empirical support for adaptive expertise.

1.1.4 Knowledge representation

As described earlier, expertise has been linked to the capability to quickly apply knowledge to particular problems. Differences in knowledge representation of adaptive experts potentially explain how adaptive experts are capable to excel in unfamiliar situations or overcome challenges such as cognitive entrenchment. In other words, adaptive experts need to be able to apply knowledge to different situations and contexts. In their literature review on adaptive expertise, Bohle Carbonell et al. (2014) summarise that knowledge representation of adaptive expertise differs from routine expertise. Namely, the abstraction of knowledge potentially differs between routine experts and adaptive experts. The argument is that existing knowledge is more readily available in a different context when it is represented at different levels of abstraction (Mylopoulos and

Woods, 2009). For instance, Barnett and Koslowski (2002) hypothesise that the superior performance observed in their study is based upon different abstraction in the knowledge representation, namely the differentiated representation of causal relation. The knowledge of adaptive expertise needs to be applicable to new contexts.

The degree of abstraction of knowledge is difficult to define in general, although it refers to a more theoretical knowledge representation (Barnett & Koszlowski, 2002). In general, abstract knowledge refers to semantic knowledge, namely the representation of knowledge in pre-defined categories (Collins, & Quillian, 1969; Anderson, 1983). For instance, semantic knowledge encompasses the notion that an instance is linked to a particular other concept. To illustrate this, Collins and Quillian (1969) use the description of birds: by inference, from knowing that a mockingbird is a bird and that birds can fly, one can conclude that a mocking bird can fly. In this case, the higher level inference that birds fly is more abstract than the circumstance that a mockingbird is a bird. While the theory of Collins and Quillian (1969) has been used in the context of elementary cognitive processes, similar concepts can be found in the context of more complex reasoning processes. For instance, Johnson-Laird (1983) introduced the theory of mental models, referring to the theory that individuals perceive situations based upon general expectations that are experience-shaped. Similar to formal logic, problems are analysed based upon premises in the form of mental models which are subsequently explored. Hence, the semantic structure of Collins and Quillian (1969) also translates into mental models, given that one can infer from a mental model that birds can fly and a mockingbird is a bird, implying that a mockingbird can fly. Higher level abstractions involve the grouping of several concepts under a more general one which contains the features that the underlying concepts share.

The bottom line is that knowledge is a crucial aspect in adaptive expertise. Therefore, the following hypothesis is stated:

Adaptive experts show a higher level of abstractive knowledge representation compared to non- adaptive experts.

The assumption is that adaptive experts more readily group concepts under a higher order concept at the cost of details which might contradict this grouping. For example, adaptive experts more readily summarise different bird animals under the heading bird. Hence, an adaptive expert takes more readily a higher level abstractive representation.

It was decided to scrutinise the knowledge representation with a card-sorting study. In the following, the method is described and the expected results/hypotheses are mentioned.

1.2 Card- Sorting Method

To investigate the hypotheses a card- sorting study was conducted. Previous card- sorting studies have shown that the method offers insights into concept representations, their structure and the interrelation between different concepts, such as hierarchical relations or the difference between concepts (Cooke, 1994). Card-sorting is a method in which an expert is asked to sort terms/concepts into piles based upon their relatedness (Cooke, 1994; Rugg & McGeorge, 1997). The concept elicitation method of card-sorting aims to identify whether an individual regards two items as being related (Cooke, 1994). It has been used to identify the mental model or knowledge structure of individuals (e.g.

Schmettow & Sommer, 2016). Rugg and McGeorge (1997) describe that card sorting is embedded in the personal construct theory (Kelly, 1955), which states that the individual categorises his/her experiences and is capable of expressing them in categorisations (e.g. Fincher, & Tenenberg, 2005).

According to Rugg and McGeorge (1997), the best results of card sorting are obtained by simply repeating the card sorting multiple times to identify all potential constructs that individuals use. The results of card sorting can differ in the number and content of criteria and categories that participants use (Rugg & McGeorge, 1997). Frequently, a dendrogram is constructed comprising clusters to identify item groups that are frequently categorised together (e.g. Schmettow, & Sommer, 2016). To create these clusters items, need to be merged (grouped). The most frequently-used methods either minimise the distance within a cluster or between clusters, or trade-off between both (Johnson, 1967; Schraagen, 1988; Schmettow, & Sommer, 2016).

1.3 Expected results

Abstract knowledge representation manifests itself in the hierarchical structure of the card-sorting study. Therefore, abstract knowledge focuses on a higher-order theoretical level which means that the cluster show less detail and those items are categorised in larger clusters. Hence, the more card-sorting items are sorted together, the more abstract knowledge representation can be measured.

It is hypothesized that adaptive experts categories concepts in clusters systematically closer to each other. The corresponding hypothesis is:

The overall distance between clusters and concepts from adaptive experts is to lower compared to non-adaptive experts.

Furthermore, it is hypothesized that abstract knowledge representation reflects itself in a lower amount of clusters on the same level of distance. The corresponding hypothesis is:

Adaptive experts create fewer clusters on a given height compared to non-adaptive experts.

Moreover, it is expected that adaptive experts indicate the aforementioned measurements of abstraction regardless of the domain of expertise. The corresponding hypothesis is:

Adaptive experts create fewer clusters and a lower overall distance compared to non-adaptive experts regardless of the domain of expertise.

Finally, it is explored to what extent qualitative differences exist between adaptive experts and non- adaptive experts.

1.4 Context of the study

In this study it has been assumed, that adaptive expertise can be measured as a result from different study programs. Two study programs were chosen. Technical medicine is linked to adaptive expertise and medicine is related to routine expertise. Even though both study programs are likely to contain elements of adaptive and routine expertise, it is expected that the technical medicine program leads to a higher amount of adaptive expertise. Next the study program technical medicine is introduced and both assumptions regarding the type of expertise are discussed in detail.

Technical medicine is a study program at the University of Twente designed to fill a gap between engineering and medicine, namely the adaption of technology in the medical process of diagnosis and/or treatment (Utwente, 2015). To achieve this, graduates are taught to become experts in the domain of medicine and medical engineering. Graduates need to develop and keep up to date with two distinct fields of expertise. Key aspects of technical medicine are the capabilities to identify medical problems and technical shortcomings. Based on these problem identifications, solutions need to be developed to solve or improve the current practice. Knowledge from one domain needs to be transferred to the other.

Technical medicine has been linked to adaptive expertise in a previous unpublished thesis (Overkamp, Groenier & Noordzij, 2014). Adaptive expertise has been linked to concepts containing flexibility, or creativity, and meta-cognitive skills (e.g. Bohle Carbonell, et al., 2014). To become successful in the field of technical medicine, ideally students develop these subsets. Creativity is needed to identify uncommon solutions to a particular problem, while meta-cognition is needed to identify whether a particular strategy applied to analyse or solve a problem is fitting, or whether the current cognition leads to a dead end. Several aspects of innovative capacity are ideally developed in technical medicine.

In addition to this, adaptive expertise has been linked to experiences in different contexts (Pulakos, et al., 2002; Han, & Williams, 2008). This goes beyond the pure opportunity to experience content from technical and medical domains. Instead, technical medicine encompasses a wider range of different problem statements compared to single expertise studies, such as medicine. Different kinds of problems statements can be described by the differentiation Dijkstra & van Merriënboer (1977) describe. The authors distinguish between categorisation problems, interpretation problems and design problems (Dijkstra, & van Merriënboer, 1997). The three types differentiate between the categorisation of instances, the relation of concepts and the creation of an “artefact”, namely a design object (Dijkstra, & van Merriënboer, 1997). The first two kinds of problems are typical in the medical domain. Symptoms or complaints need to be categorised and related to different concepts. The design problem is especially present in the technical aspects of technical medicine. The different types of problems are usually present to some degree in every problem case (Dijkstra & van Merriënboer, 1977). Dijkstra & van Merriënboer (1977) relate the different kinds of problems to opportunities to develop different experiences. For instance, categorisation, interpretation and design problems are linked to descriptive, explanatory, or prescriptive theories respectively.

Hence, in relation to adaptive expertise, technical medicine students need to apply knowledge flexibly to two different domains and different problem structures. Whereas medicine encompasses problems that can mostly be characterised by the first two types of problems, the engineering part of technical medicine encompasses problems that can be categorised as design problems.

In accordance with the aforementioned aspects, a comparison group was selected to comprise routine experts. Medicine study programs have been criticised for their rigid study program (Cooke, Irby & O'Brien, 2010). The rigid application of facts has been associated with routine expertise, since it involves applying learned procedures instead of prompting a deeper understanding and modification of these rules (Cooke, Irby & O'Brien, 2010; Hatano & Inagaki, 1986). This however, is a relative statement, indicating that technical medicine more frequently involves prompting different experiences and manners of procedure compared to classical medicine. Medicine nevertheless encompasses adaptive expertise, too.

It can be assumed that technical medicine students as well as medicine students are capable to show adaptive expertise. Nevertheless, the study of technical medicine is assumed to promote adaptive expertise whereas medicine students are promoted to show more routine expertise. In addition, medicine students are likely to have more experience with the first two kinds of problems - categorisation and interpretation problems - and they mostly gather academic experience within one domain of expertise. In comparison to adaptive experts, medicine students should additionally lack domain expertise in technical issues and should show little expertise with regard to this domain.

From a methodological perspective, the relatedness of the two groups pertaining to medical knowledge offers the advantage that the card sorting categories participants build are potentially meaningful and not random or based on superficial relations. Due to this similarity, both groups are capable to apply some aspect of long-term knowledge. By comparison, if participants have no meaningful interpretation of the terminology used in a card-sorting study, the results could become randomly based upon superficial traits (Cooke, 1994; Rugg & McGeorge, 1997). Ideally, the card sorting results represent schemas invoked from the domain perspective of the experts' groups, rather than superficially based categorisations one would expect from novices (Chi, Glaser & Feltovich, 1979). Nevertheless, card sorting studies are linked to the interpretation of the researcher (Fincher & Tenenberg, 2005).

2 RESEARCH METHODOLOGY

2.1 PARTICIPANTS

Overall, eighteen participants completed the card-sorting study. Ten participants were students of medicine, while eight studied technical medicine. In accordance with the gender distribution within the study programs, all but one male participant were female. Due to the convenience of potentially reaching more German medicine students than their Dutch counterparts, it was chosen to select this particular comparison group. Technical medicine students were Dutch, whereas medicine students were German. The technical medicine students were recruited mostly by mail or personal reference. The mean age of the technical medicine students was 24.3 years old, ranging between 23 and 26 years, while for the medicine students the mean age was 23.7, ranging between 20 and 26 years of age. All technical medicine students were in their master´s degree program. The medicine students had at least passed their ‘Physikum’, a test administered after two years of study.

2.2 MATERIALS

To prepare the card sorting study, interviews were conducted with two domain experts to elicit domain knowledge and construct the card content. The use of interviews to prepare knowledge elicitation techniques is recommended since card sorting is limited to explicit knowledge (Rugg & McGeorge; Cooke, 2004). Two problem cases were used as a basis for these interviews, selected to reflect the typical domain-specific problem for the two groups involved in this study.

In the case of technical medicine, a design problem was chosen from a radiological context. The problem used in this study was developed by Overkamp, Groenier and Noordzij (2014), asking the participant to develop a solution to the shortcomings of the frequently-used current diagnostic procedure Trans Rectal Ultra-Sound guided biopsy (TRUS). TRUS biopsy is an invasive method used to diagnose prostate cancer, whereby a needle is used to take a sample of the cancer in the prostate. Since the procedure is sometimes unsuccessful due to its limitations, alternative solutions could potentially improve the diagnostic procedure for patients and practitioners.

In the context of medicine, a classification problem was constructed asking the practitioner to identify and characterise a set of symptoms. The symptoms in this case were derived from a medical case from the Dutch medical journal “Nederlands Tijdschrift voor Geneeskunde” (Van der Naald, & Verbeek, 2015). The case describes an infection with tungiasis, a tropical parasite that settles in the skin of the feet and produces a wound similar to a corn, which becomes increasingly painful and itchy. If left untreated, other infections can occur. During the interview, a description of the symptoms was presented to the experts (Table1)

Case 1:

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.

Case 2:
Na een Tropenreis komt een cliënt met een kleine huidafwijking aan de voeten naar de huisarts. De afwijking bestaat sinds 6 weken en lijkt op likdoorns. Na verloop van tijd worden de huidafwijkingen groter, beginnen te jeuken en worden gevoelig bij het lopen. Wittige papels met een doorsnede van 5 – 10 mm zijn te zien, met een centrale zwarte crusta, omgeven door erytheem. De cliënt was op een oriëntatiereis in Tanzania, voordat de symptomen ontstaan zijn.

Table 1 Cases

The two cases essentially differ in their structure: while the first one contains a developmental problem or design problem, the latter can best be described as a classification or explanation problem (Cooke, Irby & O'Brien, 2010; Dijkstra, & van Merriënboer, 1997).

A radiotherapist and a general practitioner participated in the study and were interviewed according to the fixed probe interview scheme suggested by Shadbolt (2005; Shadbolt, & Smart, 2015). The experts were asked to briefly summarise and outline the task and its relevant aspects, describing the potential solutions and outcomes as well as the variables and rules affecting them. The interviews were transcribed and 25 concepts comprising terms or short phrases of each case were derived.

Since German medicine students are unable to understand the Dutch medical terms, the terms were translated to German by help of a German general practitioner. The German general practitioner was asked whether the translated terms reflect what they were supposed to mean in the Dutch language.

Case 1: Diagnosis of prostate cancer	Case 2: Infection with tungiasis
Consequences for patients	Infectious disease
Safety	Parasite
Chance of a sepsis (3-5%)	Bacterium
Perianal puncture	Bacterial infection
Puncturing 10-12 times	Tropical infection
Unreachable with a needle	Diabetes
With a needle one can reach the outside, but not so well the inside of the prostate	Diabetic foot'
Deformation of the prostate through contact with the needle	Antibiotic
Transrectal ultrasound	Broad-spectrum antibiotic
Endo ultrasound	Pus
MRI	Warm and red
Combination of MRI and Ultrasound	Local discrepancy
MRI guided biopsies	Diarrhoea
biopsies based on ultrasound	Red spots
MRI sequences optimised for the prostate	Ulcer
Non-invasive	Anamnesis
Image quality	History
Multifocal	General healthiness
Internal radiation	Differential diagnosis
Diagnosing prostate cancer	SOEP (short for Subjective, Objective, Evaluation, Plan)
PSA	Choice of a fitting treatment
Aggressiveness of the cancer	Medical referral
Gleason score	Blood examination
Rectum	Extended examination
Prostate cancer	Taking a smear

Figure 1 Concepts derived from the interviews

2.3 PROCEDURE

The card-sorting sessions were conducted via video conference or in person. At the beginning of the session, participants were informed about the purpose of the study and asked to sign an informed consent. Participants were informed about the card-sorting task, and it was detailed that the study investigates the knowledge representation in the context of medicine and that they could stop at any time without the need to explain themselves. They were instructed that they had to sort each case three times, during which they could freely choose a criterion to sort the terms and they were free to make as many categories as they found useful.

After the instructions, participants were randomly handed - or asked to take - one of the two card sets as a starting set. Once a sort was finished and documented, participants were asked to start categorising again, indicating again that they were completely free to choose how to categorise. Completion times varied between 30 and 45 minutes, although they occasionally took longer. Three technical medicine participants completed only two categorisations per case because the sorting took longer than initially expected (30 minutes).

2.4 ANALYSIS

Throughout the analysis, each card sort of participants was treated separately. A combination of the three sorts in a hierarchical structure would arguably have resulted in an interpretation by the researcher potentially biasing the results. As previously stated, Rugg and McGeorge (1997) indicate that card sorting can differ in terms of the number, and content of criteria and categorisations. To analyse the categorisations, the Jaccard coefficient was calculated (Capra, 2005; Schmettow, & Sommer, 2016) by dividing the number of categories containing two particular items by the number of categories containing only one of the items (Schmettow, & Sommer, 2016). To calculate the Jaccard coefficient, the statistical programming language R was used. The website Uxbooth (Salmoni, 2012) provides a basic algorithm regarding the calculation of Jaccard values. To prepare the data, each card sort was transformed in a binary table in which a ‘1’ indicated that an item was categorised within a particular category and a ‘0’ that it was not. The code was manipulated to create a copy of the Jaccard values of each individual card sort and summed up afterwards. A dendrogram was constructed, based on these values. The dendrogram agglomerates items to clusters to create a tree structure by merging the most frequently coupled items.

To create the clusters within the dendrogram, items need to be merged (grouped). As indicated in the introduction, several methods exist: The most frequently-used methods use an agglomerative procedure to define clusters (e.g. Schmettow & Sommer, 2016). The methods merge the closest groups, based on an algorithm determining the least dissimilarity between clusters, and generate the next cluster continuing from the merged clusters (Gronau, & Moran, 2007; Johnson, 1967). In this study, the unweighted pair group method with arithmetic mean (UPGMA) was applied as recommended in Tullis and Albert (2013). This method merges an item with a cluster based on the distance between this item and the average distance of items in a cluster (Punj, & Stewart, 1983). The distance between clusters in the dendrogram indicates the average distance between the items within these clusters. A higher distance indicates that the items within these clusters have been sorted less frequently together.

3 RESULTS

The study at hand explored three hypotheses by means of a card-sorting study:

1. *H_1: The overall distance between clusters and concepts from adaptive experts is lower compared to non-adaptive experts.*
2. *H_2: Adaptive experts create fewer clusters on a given height compared to non-adaptive experts.*
3. *H_3: Adaptive experts create fewer clusters and a lower overall distance regardless of the domain of expertise compared to non-adaptive experts.*

Additionally, it is explored to what extent qualitative differences exist between adaptive experts and non- adaptive experts.

Overall, the participants used between two and nine categories in each card sort. Most sorts remained flat in their structure, whereby categories were sorted on the same level, with no hierarchical distinctions. However, some category names imply deeper structures behind the categorisation. For example, in some cases the term "übergeordnet" was used, which translates into 'superordinate'. For each case, 30 card sorts were recorded for the medicine students and 21 for the technical medicine students. Similar sorts between each card sort by a single participant result in higher accumulated values for the couples that remained similar. Regarding the technical medicine case, technical medicine students used on average 5.95 categories (range = 3 – 8), medicine students used on average 4.7 categories (range = 2 – 8). In the medical case, the technical medicine students used 5.3 categories per sort, ranging between three and nine categories, while the medicine students sorted on average 5.1 categories, ranging from two to eight categories. The amount of different categories participants used differed between card sorts, indicating that different perspectives were taken or previous categories were distinguished or summed up.

The results for each hypothesis are displayed in a dendrogram and in text presented per comparison case and group. The dendrogram displays the distance between each construct.

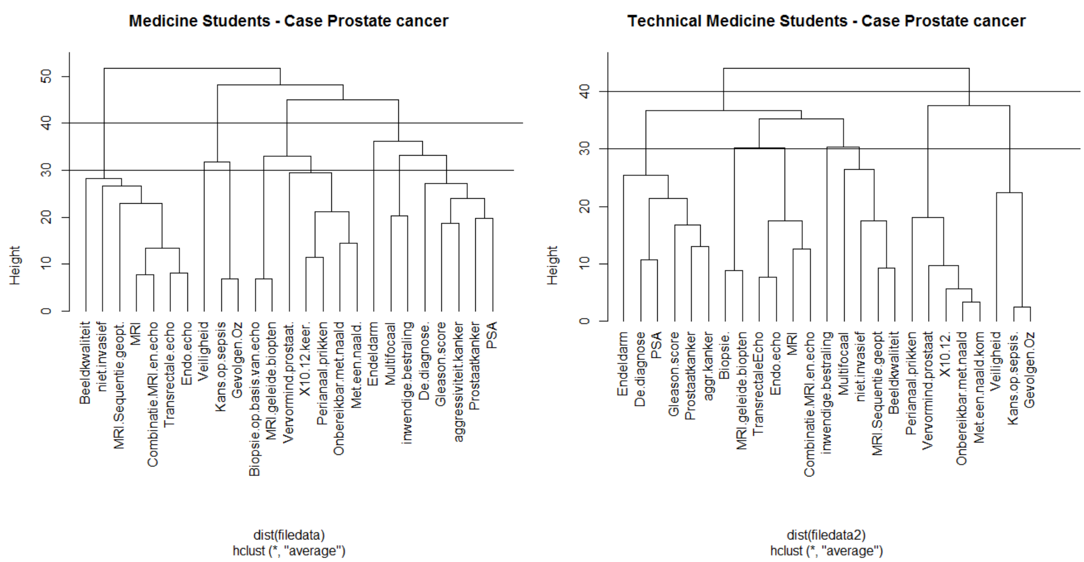

Figure 2 Dendrogram Prostate cancer case

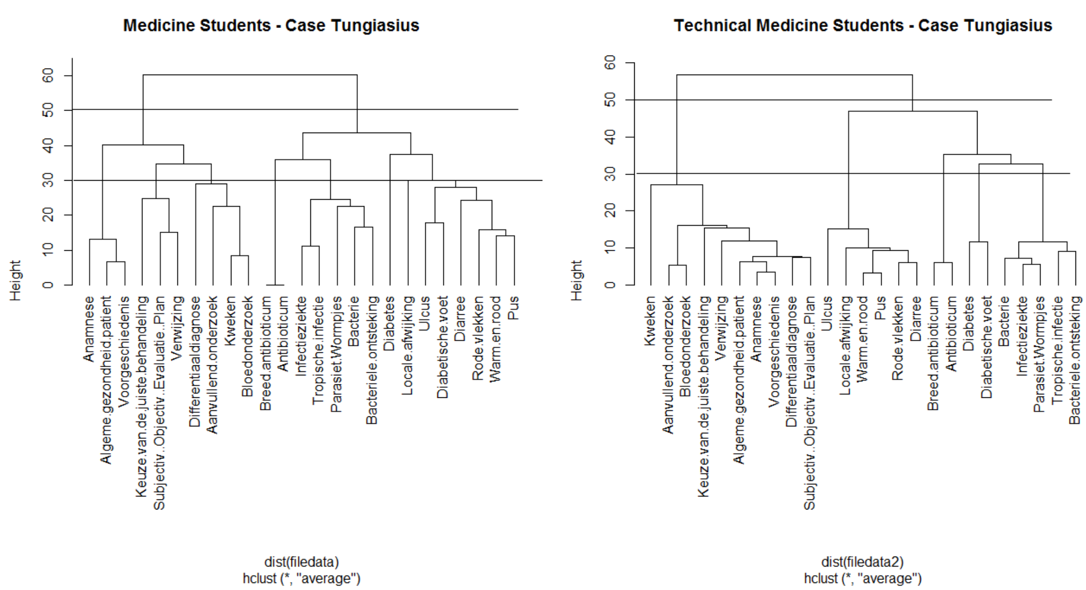

Figure 3 Dendrogram Tungiasus Case

3.1 *HYPOTHESIS 1*

As mentioned earlier, it is assumed that the distance between constructs indicates the level of abstraction of the experts' knowledge representation. An example to illustrate, there are three objects to sort; two scissors, one knife and a cup. An expert with a low level of abstraction would sort three groups: scissors, knife and a cup. Whereas an expert with a high level of abstraction would sort two groups: cutting tools and drinking vessels. Similarly, a lower distance indicates that categorisations have merged more constructs faster.

For both groups, the overall distance was lower in the prostate cancer case compared to the tungiasis case.

3.1.1 Prostate cancer case

The highest distance between two constructs was below the height 45 for technical medicine students and above 50 for medicine students.

3.1.2 Tungiasus Case

Regarding technical medicine students the overall distance was between 55 and 60, while medicine students had a distance at the level of 60.

3.1.3 Comparison between cases and participant groups

In the prostate cancer case, the technical medicine students had a lower distance between the constructs compared to the tungiasis case. The same was observed for the medicine students.

3.1.4 Differences between the two groups

Overall the results show that both groups differ in height in the prostate cancer case. In detail, technical medicine students showed a lower distance between constructs in each case. Regarding the tungiasis case, the overall height was lower for both groups. This indicates that technical medicine students show a higher level of abstraction, as indicated at the beginning of this chapter.

3.2 HYPOTHESIS 2

To investigate the second hypothesis, the amount of clusters at several heights is compared between the two groups. As illustrated in Hypothesis 1, a lower amount of clusters at a given height is interpreted as a higher level of abstraction. The amount of clusters at a given level is summarised in the histograms, Figure 4 and 5, below. The maximum amount of clusters is equal to the number of items, 25.

The histogram (Figure 4) illustrates the amount of clusters at several points of distance/height regarding the prostate cancer case for both groups. At all compared heights, the dendrogram indicates a lower amount of clusters for the technical medicine students. The closest the two groups get is at the height of 35 were both groups show five clusters.

3.2.1 Prostate cancer case

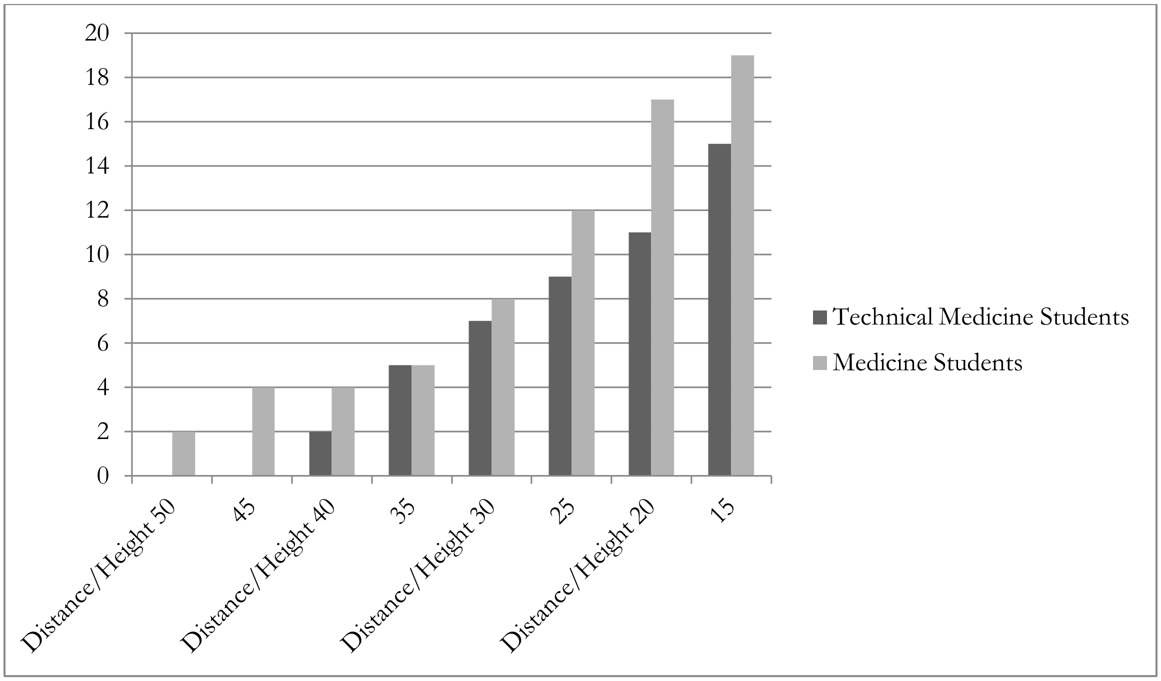

Figure 4 Histogram Cluster per Distance Prostate Cancer Case

3.2.2 Tungiasis case

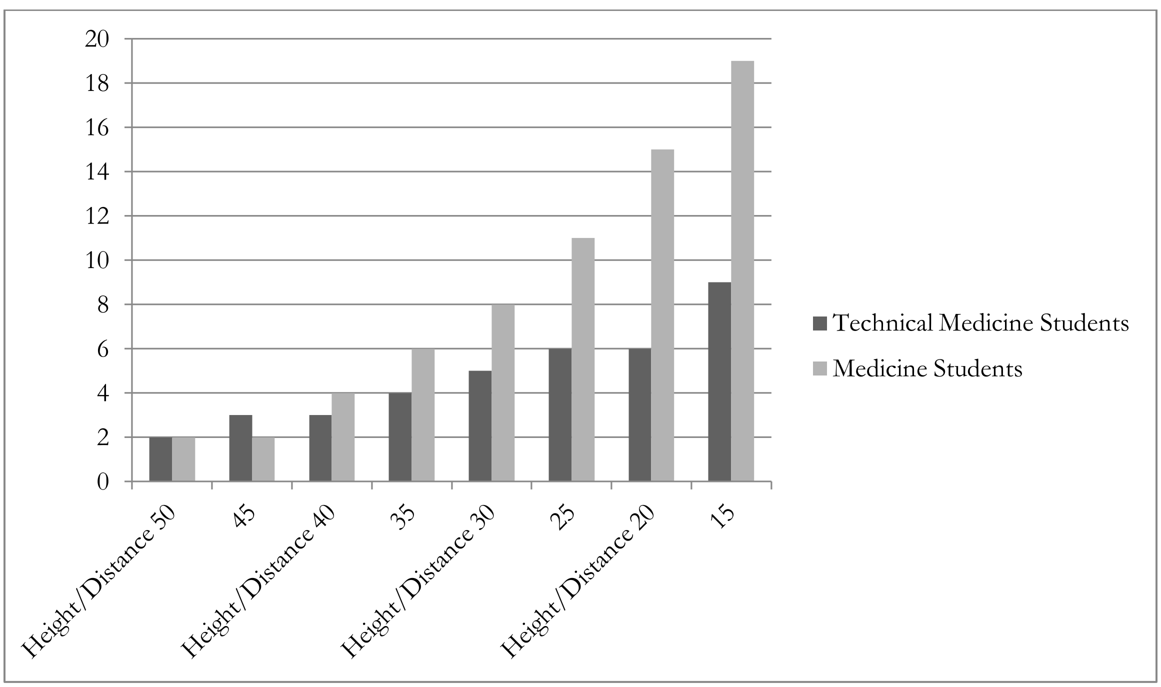

Figure 5 Histogram Cluster per Distance Tungiasis Case

The tungiasis case shows a similar tendency as the prostate cancer case. At most compared heights/distances, a lower amount of categories is observed for technical medicine students compared to medicine students (Figure, 5). Only at the height of 45, a higher number of clusters is indicated for the technical medicine students. At the lowest height, the number of clusters for the medicine students is more than double the amount of clusters the technical medicine students show.

3.2.3 Both groups across the cases

In comparison the technical medicine students show a lower amount of clusters at the same height compared to medicine students in both cases. The difference between the two cases is higher for technical medicine students compared to medicine students. In comparison a lower amount of clusters was measured for technical medicine students in the medicine case compared to the technical medicine case. Medicine students on the other hand showed a similar pattern across both cases. In summary, technical medicine students show a tendency to merge clusters earlier compared to medicine students. According to the introduced reasoning, this indicates a higher level of abstraction.

3.3 Hypothesis 3

As mentioned in the two hypotheses above, technical medicine students indicated a lower overall distance as well as a lower amount of clusters at the compared heights in both cases. Relatively, differences between the cases were higher regarding technical medicine students compared to medicine students.

3.4 *EXPLORATION OF THE QUALITATIVE DIFFERENCES BETWEEN THE TWO GROUPS*

The quantitative differences between the two groups have been described in the preceding section. In the following some aspects of the qualitative content is described to further investigate the differences in the knowledge representation of technical medicine and medicine students.

In the previous section, the attempt was made to measure abstract knowledge of students using a quantitative approach. The intention was to find out whether technical medicine students hold more abstractive knowledge representation compared to medicine students. Since the quantitative differences indicate a higher abstractive knowledge, as explained in hypothesis two, these differences should be qualitatively visible too. To repeat the example from hypothesis two: An expert with a low level of abstraction would sort three groups: scissors, knife and a cup. Whereas an expert with a high level of abstraction would sort two groups: cutting tools and drinking vessels. Similar to this we would expect higher level clusters on the same distance level for technical medicine students.

In the following, tables (2-5) are used to summarise the clusters. In the left column, the chosen distance level is displayed. In the top rows, descriptive headings for the clusters were formulated. Underneath these headings the different items are listed. In Table 2 the item clusters of technical medicine students in the context of the prostate cancer case are visible. At the height of 40 two cluster were counted. Content wise these clusters distinguish items related to “puncturing and risks” and “prostate cancer, imaging and biopsies”. At the same height, (Table 3), medicine students show four clusters, related to: “Imaging”, “safety/patient risks”, “puncturing”, and “prostate cancer” related items. In this case, the abstract knowledge representation is qualitatively visible since technical medicine students summarized aspects, such as puncturing and associated risks, as well as imaging, and biopsies related items.

At the height of 30 seven clusters are present regarding technical medicine students. These items can be described by Prostate cancer, Imaging, Patient consequences, Biopsies, Therapy, Characteristics of Imaging, Puncturing. In comparison, regarding medicine students eight cluster can be counted. These can be summarized, by Imaging, Safety, Risks, Biopsies, Puncturing, Rectum, Therapy, and Prostate cancer. Overall, two aspects can be observed in these examples. On the one hand, technical medicine students have summarised patient related concerns and prostate cancer related aspects – the single items “rectum” and “safety”. On the other hand technical medicine students have differentiated imaging related items, which medicine students have not. On the one hand thus, technical medicine students seem to have taken a higher level of abstraction, on the other not.

Distance/ Height	Item Cluster						
40	Prostate cancer/Imaging/Biopsies					Puncturing/Patient risks	
30	Prostate cancer	Imaging	Biopsies	Therapy	Qualities, Characteristics of Imaging	Puncturing	Patient consequences
	prostate cancer	Endo Ultrasound	Biopsies based on ultrasound	Internal radiation	Image quality	Perianal puncture	Consequences for patients
	diagnosing prostate cancer	MRI	MRI guided biopsies		Non-invasive	Deformation of the prostate through contact with the needle	Chance of a sepsis (3-5%)
	PSA	Combination of MRI and Ultrasound’			MRI sequences optimised for the prostate’	Puncturing 10-12 times	Safety

	Aggressiveness of the cancer	Transrectal ultrasound			Multifocal	With a needle one can reach the outside, but not so well the inside of the prostate	
	Rectum					Unreachable with a needle	
	Gleason score						

Table 2 Item-Clusters- technical medicine student - Prostate cancer case

Distance / Height	Item Cluster (Summarization Titles)							
40	Imaging	Patient Risks		Puncturing		Prostate cancer		
30	Imaging	Safety	Risks	Biopsies	Puncturing	Rectum	Therapy	Prostate cancer
	Non-invasive	Safety	Chance of a sepsis (3-5%)	Biopsies based on ultrasound	Unreachable with a needle	Rectum	Multi-focal	PSA
	MRI sequences optimised for the prostate		Consequences for patients	MRI guided biopsies	Deformation of the prostate through contact with the needle		Internal radiation	Prostate cancer
	image quality				Perianal puncture’			Diagnosing prostate cancer
	Combination of MRI and Ultrasound				Puncturing 10-12 times			Aggressiveness of the cancer
	MRI				With a needle one can reach the outside, but not so well the inside of the prostate			Gleason score
	Endo Ultrasound							
	Transrectal ultrasound							

Table 3 Item - Clusters of Medicine students – Prostate cancer case

Regarding the tungiasis case, technical medicine students show a higher amount of clusters at the height of 45 compared to medicine students. In table 4 and table 5, the clusters are summarized for both groups at the height of 50. At this stage, both groups differentiate practitioner and disease related items. At the height of 45 technical medicine students split disease related items in Symptom/Treatment and Diagnoses related clusters. At this level of height, medicine students seem to view the items at a higher level of abstraction. Nevertheless, this is the only time in the quantitative results, technical medicine students show a higher number of clusters compared to medicine students. At the height of thirty a much higher difference between the two groups emerged, with five clusters regarding technical medicine students and 8 regarding medicine students. The content of these clusters indicates that technical medicine students show a single cluster concerning practitioner related items, whereas medicine students have three. On the disease related items, only one cluster differs between the two groups. Whereas technical medicine students have summarized all symptoms, medicine students have distinguished local discrepancy from other symptoms. In summary, technical medicine students have indicated a higher level of abstraction regarding practitioner related items and symptoms.

Distance/Height	Item Cluster				
50	1. Practitioner-related items	2. Disease-related items			
30		2.Symptoms	3.Treatment	4.Diabetes	5.Diagnoses/Causes
	Anamnesis	Pus	Antibiotic	Diabetes	Infectious disease
	(Medical) History	Warm and red	Broad-spectrum antibiotic	Diabetic foot	Parasite
	general healthiness	Local discrepancy			Bacterium
	differential diagnoses	Diarrhoea			Bacterial infection
	SOEP	Red spots			Tropical infection
	(short for Subjective, Objective, Evaluation, Plan)				
	Choice of a fitting treatment	Ulcer			
	Medical referral				
	Blood examination				
	Extended examination				
	Taking a smear				

Table 4 Clusters of technical medicine students- Tungiasus Case

Distance/ Height	Item Cluster							
50	Practitioner-related items			Disease-related items				
30	Patient background	Method/Decisions	Examinations	Treatment	Diagnosis	Diabetes	Characteristic of a symptome	Symptoms
	History	Choice of a fitting treatment	Extended examination	Antibiotics	Bacterial infection	Diabetes	Local discrepancy	Pus
	Anamnese	SOEP	Differential diagnosis	Broadband antibiotics	Bacteria			Warm and red
	General health	Medical referral	Taking a smear		Parasite			Red spots
					Infectious disease			Diarrhoea
					Tropical infection			Ulcer
								Diabetic foot'

Table 5 Clusters of medicine students - Tungiasis Case

4 DISCUSSION

In the introduction it was hypothesised that *adaptive experts show a higher level of abstractive knowledge representation compared to non- adaptive experts.* To scrutinise this research question a card sorting study was conducted with two groups and three hypotheses. The discussion starts with the last hypothesis which states that:

Adaptive experts create fewer clusters and have a lower overall distance compared to non-adaptive experts regardless of the domain of expertise.

With regard to the two groups and cases in this study, technical medicine students needed to create fewer clusters and have a lower overall distance compared to medicine students in the Prostate Cancer case, as well as the Tungiasis case. The results of this study indicated that technical medicine students have a higher level of abstraction in both cases, as seen in the results of hypothesis 1 and hypothesis 2. This will be explained in the following paragraph.

Hypotheses 2 investigates whether adaptive *experts create fewer clusters on a given height compared to non-adaptive experts.* In both cases, technical medicine students indicated a higher level of abstraction compared to medicine students as indicated by the number of clusters at a given height. Abstractive knowledge representation is reflected in the level of abstraction an expert views a particular set of knowledge. A higher level of abstraction is reached, when items are viewed on a higher order criterion. To take the example from the result section: an expert with a low level of abstraction would sort three groups: scissors, knife and a cup, whereas an expert with a high level of abstraction would sort two groups: cutting tools and drinking vessels. Technical medicine students indicated a higher level of abstraction as measured in the number of clusters at a given distance, compared to their medicine counterparts.

A similar argumentation follows hypothesis 1, which states that *the overall distance between clusters and concepts from adaptive experts is lower compared to non-adaptive experts.* Since the overall distance measures the highest distance between two items we can assume that the lower the overall distance between items, the higher the number of different items that have been categorized together. Therefore it can be stated that knowledge representation is more abstract because different items have been sorted together more frequently. In relation to technical medicine students, we observe a higher level of abstraction in the card sort because the overall distance in both cases is lower compared to medicine students.

Overall, the quantitative results suggest that technical medicine students used a higher level of abstraction throughout the card sorting study. In this study, technical medicine students have been assumed to represent adaptive experts. Hence, the study gives minor indication to the role of abstract knowledge representation in adaptive expertise. Mylopoulos and Woods (2009) hypothesized that higher levels of abstract knowledge representation would enable adaptive experts to apply knowledge to different contexts. In comparison to beginners, Chi, Feltovich & Glaser (1979) indicated that experts apply knowledge representation to analyze and categorize problems. Under the hypothesis of Mylopoulos and Woods (2009), knowledge representation would not only be an important characteristic to analyze problems, but also to solve them.

Throughout the introduction, the role of adaptive expertise has been set in educative settings. Cooke, Irby, & O'Brien, (2010) have criticized medicine study programs for the emphasis on rigid knowledge replication. In this study, some indications are provided that rigid study programs can indeed benefit from loosening their study programs. Adaptive expertise has been linked to the opportunity to make experiences across different settings and contexts (Pulakos, et al., 2002; Han, & Williams, 2008). Classic medical curricula could benefit from introducing an emphasis on an application of knowledge.

4.1 Limitation

First of all, the question arises, whether the quantitative differences can be securely attributed to differences in the abstractive knowledge representation. Throughout the Prostate cancer case, technical medicine students had often a single cluster less compared to medicine students. Additionally, inspecting the qualitative data, it is sometimes not identifiable whether differences in the clusters arise from the perspective taken, rather than the knowledge representation. To illustrate this, the most prominent case might be the Tungiasus: Whereas medical students have distinguished practitioner related items, technical medicine students did not. Although on first sight, this seems to point towards a more abstract knowledge representation, one might also state that technical medicine students do not have a similar domain knowledge regarding practitioner related task, compared to medicine students. In summary, it is difficult to determine, whether differences in the two cases arise from the backgrounds of study. Future studies should investigate inter individual differences, rather than group differences. However, at the moment valid and reliable measurements of adaptive expertise are scarce, since it is yet open which aspects determine adaptive expertise. These difficulties need to be kept in mind.

Another difficulty arises from the definition of expertise. The identification of experts has been a debate in the expertise literature in general. In this study the two groups were chosen based on study programs. For instance, Anders Ericsson and Towne (2010) illustrate the difficulties associated with the definition of expertise in general, indicating discussions concerning whether years of experience is linked to expertise and other measurements. Rather than true routine or adaptive expertise, students in general are likely at an intermediate level, which has been linked to differences to experts with significant experience in a particular field (Anders Ericsson & Towne, 2010). Future studies ideally include other measurements of adaptive expertise, to make profound conclusions.

Regarding reliability, this study is limited in several aspects. First of all, the number of respondents included in this study per group is lower than recommended, with eight and ten participants. A recommendation for future research can be taken from Tullis and Woods (2004), who reported that the difference between card-sorting results is saturated around the number of 25-30 participants. Regarding the small population of technical medicine students, this is a time-consuming task that could not be achieved within this study. Another aspect concerning reliability is the choice of the card-sorting methodology to conduct a repeated card sort as recommended by Rugg and McGeorge (1997). In hindsight, a hierarchical card sort asking to group or split existing categories would potentially have created more reliable results. Finally, the difference between items likely resulted in a limited amount of differentiation between card sort and hence a limited reproducibility.

4.2 Conclusion

In conclusion, this study indicates that abstract knowledge representation is potentially a defining characteristic of adaptive expertise. Nevertheless, further research of this topic is needed because several limitations constrain this study. This study has provided a first step into the role of abstractive knowledge representation. Future research should focus on inter individual differences and identify whether rising adaptive expertise is linked to more abstract knowledge representation.

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