Knowledge and skills acquisition in medical students

Cecilio Fernandes, Dario

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GENERAL DISCUSSION

The general aim of this thesis was to provide further insight into aspects of the curriculum in relation to students' knowledge development and skill acquisition, by respectively studying students' performance on the progress test and by investigating the effect of spacing training sessions and different types of feedback. Since studying aspects of the curriculum is complex, different methodologies were used, looking through different lenses. Retrospective, quasi-experimental, systematic review and experimental studies were performed to examine the following research question:

How do aspects of the curriculum relate to students' knowledge development and skill acquisition?

MAIN FINDINGS AND DISCUSSION

This thesis examined different types of learning (the first part of this thesis addressing knowledge development, and the second part skill acquisition and retention), at different levels (from the effect of feedback characteristics to the effect of massed or spaced curricula) using different theories or frameworks. The next section will describe how a cognitive interpretation may help explain the findings and show that a more detailed analysis of the type of cognitive processing involved may be useful – both for research purposes and for practical applications. Before discussing the main results in light of cognitive psychology, a short overview of the theory will be provided.

COGNITIVE PSYCHOLOGY

A fundamental distinction in cognitive psychology is the distinction between declarative and procedural knowledge.[1,2] Declarative knowledge refers to knowledge about facts or events ("knowing what") and can be consciously inspected. Procedural knowledge refers to "knowing how" and cannot be consciously inspected. Declarative knowledge decays over time, which means that it is possible to forget knowledge when it is not used often enough, whereas procedural knowledge is not subject to decay.[1,3]

Regarding **knowledge acquisition**, the most important mechanism is the creation of new declarative knowledge (chunks). This new knowledge is connected to other declarative knowledge, so that a network of declarative knowledge is formed. For example, when one learns that the heart has four chambers, the names of the four chambers will be connected to the declarative knowledge of the heart (which is connected to the other elements in the declarative network). Importantly, if the knowledge is not used (i.e. not retrieved), that information (e.g. the names of the heart chambers) will decay over time, so it may no longer be possible to retrieve it. Although knowledge *acquisition* is based on the creation of new declarative knowledge and on the connections between the knowledge elements, *retention* is based on retrieving that knowledge (for more information see Cnossen[4]).

Different from knowledge acquisition, **skill acquisition** requires both declarative and procedural knowledge. Skill acquisition usually starts with declarative knowledge (mostly in the form of instructions).[3] Practice on a skill will slowly transform declarative knowledge into procedural knowledge; this process is known as proceduralization.[1,5] Procedural knowledge has an IF-THEN format, stating the conditions (IF) that will trigger the actions (THEN). The mastery (or automatization) of the skill will happen when the skill is in the procedural format (for more information see Cnossen[4]), when the conditions will almost automatically trigger the associated actions.

KNOWLEDGE DEVELOPMENT

In **Chapter 2** and **3** the relation between various aspects of the curriculum and knowledge development was explored. Although a number of aspects of the curriculum were studied in **Chapter 2**, only two aspects of the curriculum seem to have a relation with students' knowledge development: the presence of a pre-internship course and the concentration of the discipline in one block. Subsequently, in **Chapter 3**, we compared the effect of teaching students in a concentrated semester versus using a spaced format, in one medical school. In line with the results of **Chapter 2**, **Chapter 3** also demonstrated that concentrating a discipline in one block benefits students' knowledge development.

This is a surprising finding. Research in cognitive psychology has consistently demonstrated that spaced training improves long-term knowledge retention,[6] in tasks such as verbal recall,[7] English as a second language,[8] reading,[9] biology,[10] mathematics,[11] and medical knowledge.[12] The theory behind these findings is that declarative knowledge is subject to decay,[1,2] so it is important that students repeat their learning material on time, so they do not forget it. This implies that the time between re-studying is key:[14] If the time between re-studying sessions is too large, declarative knowledge will decay until a point where it is no longer possible to retrieve it. Also note that it is easier to retrieve declarative knowledge when it has many connections with other declarative knowledge (network), because declarative knowledge may be retrieved using different routes.[15,16] This elaboration process would thus provide redundancy in the declarative network.[18] These considerations has led Schmidt to argue that to facilatate students' learning three conditions should be met: (1) activation of prior knowledge, (2) provision of a context similar to the future professional context and (3) elaboration.[17]

So, an interesting question is therefore why students benefitted more from a massed curriculum than from a spaced curriculum. The answer may lie in the details of how the curricula was actually designed. The massed curricula studied in **Chapter 2** and **3** was designed in such a way that the content repeats itself over time and deepens understanding of the content, known as spiral curriculum.[13] Furthermore, the "massed" curriculum was spread over a block of ten weeks. Thus, the spacing effect was also present in the massed curriculum (spiral and ten weeks).

When looking at the concentrated and spaced curriculum, it seems that the gap between study sessions in the spaced curriculum may have been too long. So students in the spaced curriculum may have forgotten the declarative knowledge because of this long delay, The long delay may also have hampered these students' activation of prior knowledge when studying new materials. While students in the massed curriculum may have studied related content before declarative knowledge decay, and therefore also had more opportunity to elaborate on the materials since the topic would be revisited early enough (before decay), the students in the spaced curriculum were denied these benefits.

So, interestingly, the only two aspects shown to benefit students' knowledge development in **Chapter 2** and **3** are related to repeating the learning material on time before students forget it. This not only explains the advantage of the massed curriculum over the spaced one in our studies, but also why adding a pre-internship course had a positive relation with students' knowledge development: it helped students retrieve their previously studied declarative knowledge.

Medical students do not only acquire knowledge, but they are also expected to apply knowledge. In **Chapter 4**, the development of students' ability to apply their knowledge was investigated. Our results demonstrated that students develop their ability to apply knowledge throughout medical school. Whereas at the beginning of medical school, students only recall or have a minimal understanding of their knowledge, in the end, students are able to apply their knowledge. This finding may be explained by the distinction between knowledge recall and application, which lies in the relative amount of declarative and procedural knowledge needed. Recalling facts and events is mostly supported by declarative knowledge. Applying knowledge, however, requires students to synthesise all the information and retrieve the correct declarative knowledge (i.e. diagnoses), which is mostly supported by procedural knowledge. Whereas recall only requires retrieving declarative facts (e.g. the heart has four chambers), the application requires both declarative and procedural knowledge (e.g. clinical reasoning). Students need first to acquire the declarative knowledge and "practice" in using their knowledge in order to create specific procedural knowledge to deal with more complex cases. Interesting enough, the underlying process of applying knowledge is very similar to skills acquisition.

MEDICAL SKILL ACQUISITION

In this thesis, we investigated two different aspects of the curriculum that could optimise students' skill acquisition and retention. In **Chapter 6**, we reviewed evidence that spacing training sessions benefits skill retention for simple tasks (e.g. suturing) as well as complex tasks (e.g. laparoscopic knots). In **Chapter 7**, our results showed that during acquisition, students benefited more from expert feedback, but retention was better when students received multiple sources of feedback.

Medical skills are complex and different skills require different amounts of declarative and procedural knowledge. The difference between very simple and highly complex skills lies in the amount of declarative and procedural knowledge that is necessary for the task: more complex tasks require more declarative and procedural knowledge than more simple tasks. Since highly complex skills require more declarative knowledge, they should benefit more from spacing the training sessions than very simple skills. Then, it is evident that optimal skill training will depend on the complexity of the skill (**skill dependent**). Also, teaching and learning strategies are different for declarative and procedural knowledge. When the knowledge is in a declarative format, spacing the training sessions should be preferred.[19] When the knowledge, however, is in a procedural format, massed practice should be preferred.[19] The optimal source of feedback will also depend on the complexity of the skill.[20] Although suturing and performing a transthoracic echocardiogram, for example, both require biomedical knowledge and perceptual-motor skill, the amount of biomedical knowledge and the amount of perceptual-motor skill necessary is different. In that sense, augmented visual feedback, which is added external visual feedback, may not benefit students' suture skill retention in the same way as for the transthoracic echocardiogram because the amount of perceptual-motor skills differs: whereas simple motor skills benefit from feedback at the end of the session (terminal feedback), complex motor skills benefit from feedback during the training session (augmented feedback) (for a review see Sigrist et al.[21] and see Wulf and Shea[20]). Thus, dividing the components of skill into declarative and procedural knowledge may be a way to optimise skill training,[19] since it allows us to use the best teaching strategies based on the type of knowledge necessary.

METHODOLOGICAL CONSIDERATIONS

The studies in this thesis took advantage of a naturalistic setting, and also used experimental design as well as systematic review. This diversity in methodological design allows investigating the educational choices at different levels, ranging from a controlled environment to a synthesis of knowledge. However, the methodology should also be taken into account when interpreting the findings of this thesis. First, the methodology used in **Chapter 2, 3** and **4** were only explorative and in a naturalistic setting. **Chapter 5** and **7** took a more experimental approach by controlling confounders and manipulating specific variables; thus, the findings presuppose causality. **Chapter 6** was a systematic review in which the findings are more robust, since it gathers evidence from different studies regarding a particular subject, in this case spacing of training sessions.

Regarding usage of the naturalistic settings, most of the students' outcomes we looked at were from the progress test. Although these findings are more generalizable to the education setting, increasing the so-called ecological validity,[22] the results do not presuppose causality. In naturalistic settings, many other factors may have influenced our findings, which are difficult to control for; thus, identifying whether an observed effect can be attributed to an aspect of the curriculum is often impossible.[23,24] Nevertheless, the findings of our naturalistic studies can be very informative and generate new ideas and hypotheses.

Regarding the usage of experimental design, the strength is that only one variable is manipulated, allowing a direct study of the phenomena. The replication of experimental research, however, in a naturalistic setting has been questioned, especially in medical education.[25] Although the findings of experimental research investigate causality, the implementation in a naturalistic setting should take into account the many variables that are not present in the experimental study.

All the studies of this thesis were conducted in the Netherlands. **Chapters 2, 3** and **4** took advantage of the Dutch Progress Test. The Progress test is a unique collaboration between Dutch medical schools; thus, the particularity of the test as well as the medical schools should be considered. Also, **Chapters 5** and **7** were also conducted in the Dutch context. This specificity of the Dutch setting may decrease the generalizability of the findings of this thesis.

PRACTICAL IMPLICATIONS

Supporting students' knowledge development

Although formulating implications based on the results of a naturalistic setting presupposes causality which cannot be proven, one robust finding is worthwhile addressing.

Results of **Chapter 2** and **3** suggest that clinical disciplines that build on basic knowledge, such as oncology, may suffer from spacing the content throughout the preclinical phase. Probably, students do not possess the necessary basic knowledge when encountering chunks of the disciplines, requiring an extra effort from students to integrate the necessary knowledge when it is presented in small parts over a longer period of time. Also, one should realise that when the curriculum is already designed to repeat the material over time, and spacing the discipline too much may be detrimental to students' knowledge development compared to concentrating it in one block. It is an empirical question what the optimal spacing is in medical school.

Designing skill training

The findings of this thesis could potentially improve skill training. Skill training often focuses on the acquisition of medical skill. However, this thesis demonstrated that different perspectives should be considered when looking at skill retention. It is imperative that the focus on skill training shifts from acquisition to retention, especially when students may not have the opportunity to practice their skill frequently.

When designing a skill training one should consider how often medical students will perform that skill, and that medical skills are complex and often require a different amount of knowledge. Skills that are often performed by medical students (e.g. taking blood pressure) should focus on the acquisition whereas skills that are performed less often by medical students should focus on retention. Whereas a skill training that focuses on students' acquisition would benefit from a massed training, a skill training that focuses on students' retention would benefit more from spacing the training sessions (**Chapter 6**). Also, as demonstrated in **Chapter 7,** the feedback that students need may differ when focusing on acquisition rather than retention. Thus, the findings from **Chapter 6** and **7** suggest that the optimal skill training may be **stage-dependent** (acquisition vs retention).

The complexity of the task should also influence the specifics of skills training. Although making a transthoracic echocardiogram and suturing require similar skills (e.g. perceptual-motor and perceptual-cognitive skills), they differ in the amount and type of perceptual-motor skills and the amount of declarative knowledge. Such differences in the complexity of skills will have two important implications. First, the spacing between training sessions should be different, since highly complex skills would benefit more from spacing the training sessions. Second, the type of feedback may differ. For example, augmented visual feedback may not benefit students' suture skill retention in the same way as the transthoracic echocardiogram. Therefore, the optimal skill training may be **skill dependent**.

In summary, when designing a skill training, the optimal training is:

1. **skill dependent**: the complexity and nature of the **skill**: complex skills that require a lot of declarative knowledge benefit from spacing the training sessions; skills that are simple can be trained in massed sessions;
2. **stage dependent:** the frequency that the skill will be performed in the future determines whether the focus should be on skill **acquisition or retention**: when practiced frequently, the focus can be on acquisition, for example in massed training sessions; training sessions for infrequently used skills should be repeated over time.

Progress Test

This thesis also has practical implications for the progress test. First, the progress test was used as a tool to investigate the effect of aspects of the curriculum on students' knowledge development (**Chapter 2** and **3**). Also, the progress test could potentially be used for monitoring curriculum interventions or even experimental studies regarding knowledge development. Second, this thesis also investigated the used of the question mark option in multiple choice question (**Chapter 4** and **5**). Our results demonstrated that the educational aspect of the question mark might be restricted to novice students (**Chapter 4)** and that the use of the question mark option comes at a psychometric cost, because it increases the construct-irrelevant sources of variance (**Chapter 5**). This increase produces more items that are problematic and decreases the reliability of the test. Taking into account the restricted educational benefit and the psychometric problems caused by the use of the question mark option, perhaps it is necessary to rethink either the use of the question mark option or increase the penalty when students answer a question incorrectly. The latter would decrease students' guessing since the penalty would be higher. Increasing the penalty, however, could penalise students with more knowledge, since they are less likely to guess.[26] The question mark option has repercussions especially for novice students, because, in the context of the progress test, students at all stages take the same test at end level. This forces novice students to guess instead of acknowledging what they do not know.[27]

An alternative to the question mark option may be the use of a computerized adaptive test. A computerized adaptive test is a form of computer-based assessment in which an algorithm chooses the next question based on the level of knowledge of students.[28-30] In that way, students would only answer questions that are near their level of knowledge; thus, students should try to answer all the questions. While increasing the reliability of the test, computerized adaptive test also increases students' engagement by making all the questions meaningful.[31] Thus, it seems logical to explore the computerized adaptive test instead of using the question mark option.

Most studies regarding the computerized adaptive test have been focusing on the technical aspects, for example when the test should be finalized (for example, see Chang[30]). Although the technical aspects are necessary for a good computerized adaptive test, it is also important to understand the cognitive process behind each question, which may lead in designing a test *for* learning instead of *of* learning. For example, if it is desired to promote knowledge application, different strategies may be necessary, since knowledge application is mostly regulated by procedural knowledge. Thus, it is worthwhile pursuing the underlying cognitive process necessary to answer a knowledge test to be able to design optimal adaptive tests.

CONCLUSION

This thesis aimed to investigate the relation between various aspects of the curriculum with students' knowledge development and skill acquisition. This relation is at the core of medical education and a further understanding could possibly improve teaching and learning strategies. This thesis has demonstrated how and when the use of the spacing effect benefits students' knowledge development and skill acquisition; the development of students' ability to apply knowledge; the influence of the "I don't know" option on students' score; and, finally, that different sources of feedback for skill acquisition and retention is needed. In addition to the main findings, this thesis also showed how cognitive theory could provide further explanations for our findings to help understand what at first seems contradictory findings. Cognitive theory also provided a useful distinction between declarative and procedural knowledge, which may be a way to optimize skill training, since it allows us to use the best teaching strategies based on the necessary types of knowledge.

The use of cognitive theory to guide research and educational practice seems a logical next step. Understanding the best teaching strategy for the different types of knowledge (declarative and procedural) could potentially improve our teaching and learning strategies.

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