Book	Devetak I., Glažar S.A. (eds) Applying Bio-Measurements Methodologies in Science Education Research. Springer, Cham. https://doi.org/10.1007/978-3-030-71535-9_9
	The final authenticated version is available online at
DOI	https://doi.org/10.1007/978-3-030-71535-9_9
CITATION	Södervik I., Vilppu H. (2021) Case Processing in the Development of Expertise in Life Sciences-What Can Eye Movements Reveal?. In: Devetak I., Glažar S.A. (eds) Applying Bio-Measurements Methodologies in Science Education Research. Springer, Cham. https://doi.org/10.1007/978-3-030-71535-9_9

Case processing in the development of expertise in life sciences - what can eye movements reveal?

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ABSTRACT

Future experts of life sciences need adaptive and flexible reasoning skills in solving remarkably complex, multidisciplinary and unexpected problems, such as pandemic of severe infections, antibiotic resistance, climate change and biodiversity loss that will require innovative ways of reasoning, and ability to use knowledge and skills adaptively in unforeseen and adverse contexts. This requires promoting of so called adaptive expertise, which is considered as separate dimension in the development of expertise that needs to be intentionally supported during higher education. In that, case tasks can be beneficial, since effective case processing and knowledge restructuring are considered to be the key concepts of expertise development. In this chapter, we synthesize the results from two of our studies, employing eye-tracking method, in which routine and non-routine text-based case tasks were utilized in investigating the processing and problem-solving among medical actors with different levels of expertise. Our results show that students and more experienced actors' processing patterns differed during reading case description texts. Generally, experienced actors and those students, who were more successful in the case task, processed the texts faster. Further, the level and quality of basic biological knowledge seemed to be related to the success of students in problem-solving case task. Additionally, the script activation seemed to be detectable from participants' eye movements. These results shed light on knowledge integration and problem-solving through case processing and show that eye tracking provides interesting insight in that. The results should have an impact on advancing the instruction of life sciences in higher education, where it is imperative to educate future experts to be able to work efficiently both in predictable and especially in unpredictable circumstances.

Key words: Case; Life sciences; Eye tracking; Adaptive expertise; Expert; Novice

INTRODUCTION

The quality of life science experts' work drastically contributes to the well-being of human society and the whole globe in numerous levels and hence, fostering the development of expertise is a goal of utmost importance in life sciences at universities. Future experts of life sciences need adaptive and flexible reasoning skills in solving remarkably complex, multidisciplinary and still unpredictable problems, such as pandemic of severe infections, antibiotic resistance, biodiversity loss and climate change that will require innovative ways of reasoning, as well as ability to use knowledge and skills adaptively in unforeseen and sometimes even in adverse contexts. In addition, frequent changes in the current work environments as well as rapidly changing society calls for experts who both possess the required domain expertise and can quickly overcome changes and are able to update their competencies (Bohle Carbonell, Stelmeijer, Könings, Segers & van Merriënboer, 2014). In that, future experts need reasoning skills that exceed the conventional and traditional ways of thinking, i.e. adaptive expertise (Hatano & Inagaki, 1986). However, universities are often criticized for not producing graduates with sufficient adaptability or ability for innovations, although graduates typically succeed well in familiar tasks (Gube & Lajoie, 2020).

The challenge is that according to current understanding, expertise is mostly domain-specific, meaning that it hardly transfers to novel tasks or other domains (Bertram, Helle, Kaakinen & Svedström, 2013). Therefore, supporting the development of expertise at universities requires meaningful instructional operations that support learning of reasoning skills relevant for particular discipline. Currently, the development of expertise is suggested to require domain-specific processes at different levels: a) conceptual understanding b) knowledge integration and c) learning the links between theoretical knowledge and practice (Boshuizen & Schmidt, 2018). During the first stage of expertise development, students acquire large amount of concepts that are relevant for particular discipline and link them in a semantic knowledge network. Gradually, more concepts are added to the network and refined, and more and better connections are made between the concepts that activate frequently. Repeated activation of connections results in knowledge integration, formation of so called macro-concepts (for example biodiversity, evolution or photosynthesis), in which knowledge networks are organized in a way, where large amount of lower level conceptual details are clustered under higher order concepts. Knowledge integration enables experts, for example, to effectively retrieve large amount of information from their knowledge network, because of direct links that can be made between the first and last concept in certain line of reasoning, skipping some intermediate details (Boshuizen & Schmidt, 2018). This type of processing sort of clears up cognitive space allowing experts to exceed typical cognitive restrictions, such as a very limited working-memory capacity (Boshuizen & Schmidt, 2018).

At the further stage of knowledge integration, automaticity to learned tasks and routines starts to play a role, which allows learners not to be overwhelmed by the continual processing of previously learned material (Bransford, Brown & Cocking, 2000). In medicine, for example, it has been well established that this phase in the development of expertise leads to a situation, where the students do not actively use that much basic biological knowledge while reasoning, but operate more actively with macro-concepts and generate certain types of 'fast tracks' for reasoning, i.e. scripts (Boshuizen & Schmidt, 2018). However, utilizing of 'fast tracks' and routines is a two-edged sword: on one hand it makes routine cognitive processing more effective enabling exceeding of limits of our cognitive capacity, but on the other hand, it may be impediment to adaptability (Ericsson, 1996, 1998; Weisberg, 2006). For example, under certain conditions, cognitive biases, such as a tendency to view situations or problems as simpler than they really are—leading to misconceptions and inferior performance, have been detected (Feltovich, Spiro & Coulson, 1997). Thus, it seems necessary to take these into account when designing instruction at universities, because the concern is that unless these tendencies are actively resisted, the education may continue to educate graduates who possess expert knowledge, but cannot reliably access or apply it innovatively in novel situations (Gube & Lajoie, 2020; Hatano & Oura, 2003; Sternberg, 2003).

Aforementioned findings have led to a field of study of qualitatively different types of expertise: 'routine' and 'adaptive' expertise (Hatano & Inagaki, 1986). Research has noted that as routine experts continue improving their fluency and efficacy over time, adaptive experts have superior abstract and theoretical conceptual understanding as well as flexible access to their interconnected knowledge networks allowing them to respond to novel situations more effectively (Bohle Carbonell et al., 2014; Schwartz, Bransford & Sears, 2005). Thus, adaptive expertise is considered as fundamentally different conception of professionalism instead of 'the next step' following so called routine expertise. However, despite agreement that adaptive expertise is a worthy goal of university education (Hammerness, Darling-Hammond & Bransford, 2005) relatively little is currently known about adaptive expertise capabilities of university students, nor about ways to develop adaptive expertise within university education related to learning of life sciences. Understanding the distinctions between processing of routine and non-routine problem-solving may shed light for the development of adaptive expertise. Hence, the purpose of this chapter is to examine and compare findings from our previous studies related to the development of expertise in the context of life sciences including medicine. In these studies, eye-tracking method was utilized in investigating the processing of text-based cases among actors with different levels of expertise.

Cases in supporting the development of adaptive expertise in learning of life sciences

Based on previous research, expertise is, to a large extent, domain-specific, meaning that experts in a specific domain do not develop problem-solving skills that could be effectively applied across domains. Instead, knowledge and the associated skills to use the knowledge develop simultaneously and interdependently (Boshuizen & Schmidt, 2018). Therefore, the use of authentic, discipline-specific case tasks can have potential to effectively support learning especially in the early stages of education, when learners have to do abundantly reasoning related to conceptual knowledge and when real hands-on problems can still be overwhelming (see e.g. Boshuizen & Schmidt, 2018; Boshuizen, Gruber, & Strasser, 2020).

Case tasks can be defined as descriptions of specific events or problems that are drawn from the real world of professional practice (Ramaekers, van Keulen, Kremer, Pilot & van Beukelen, 2011). Furthermore, case tasks should require activation and meaningful linking of learners' prior knowledge so that new knowledge can be effectively connected to existing knowledge structures (Boshuizen & Schmidt, 1992). Solving them should require the similar mental activities and processes that are faced later in real work life (Brown, Collins & Duguid, 1989). In real life situations, for example, not all required information is typically available in the beginning of the problem-solving situation, but becomes available step by step requiring evaluation of information during the action. This process relates to a script-verification process in which the expert attempts to determine whether the activated script or any of the activated scripts adequately fits the findings until all available information is received (see e.g. Charlin, Boshuizen, Custers & Feltovich, 2007). Even more importantly, in real settings, experts must address complex and multifaceted cases and therefore they should include contingencies, complexities, and dilemmas requiring differentiating of relevant substance and aspects from not-so-relevant, competing noise. Effective case processing and knowledge restructuring are considered to be the key concepts of expertise development (see Boshuizen et al., 2020), and thus, learners' knowledge structures need to become organized in a way that enables effective processing of information.

Most part of the research related to cognitive adaptations during expertise development has been conducted in medical domains (see e.g. Boshuizen & Schmidt, 1992; de Bruin, Schmidt & Rikers, 2005; Feltovich & Barrows, 1984; Kuipers & Kassirer, 1984; Patel, Evans & Groen, 1989; Schmidt & Boshuizen, 1993; Schmidt & Rikers, 2007). However, based on the recent extensive review related to the theory of knowledge restructuring through case processing, similar cognitive processes and transitions on a way towards expertise seem to be relevant also across domains (Boshuizen et al., 2020). Therefore, although also majority of studies related to the role of learning by cases during the development of expertise is conducted in medical domain (including the two example studies presented in this chapter), the findings can be somewhat generalized to other scientific fields too. Respectively, medicine has a long history in utilizing different problem-analysis methods in their instruction, but since knowledge structuring through case processing takes place in all domains, some of these features could well be adapted for instruction in other disciplines too.

During the last decades, classroom practices in medicine, such as in several other disciplines at universities too, have increasingly been evolving from content-centered traditional lectures, where students often rather passively listen to the teacher, towards learning-centered environments that facilitate students' active and personal knowledge construction (Vilppu, Södervik, Postareff & Murtonen, 2019). Furthermore, different pedagogical approaches have been developed that situate operating with certain real-life problems, dilemmas or questions in the core of learning situation. Such specific instructional approaches are for example problem-based learning (PBL) (see Barrows & Tamblyn, 1980), case-based learning (CBL) and inquiry learning (IL), which all are qualitatively different approaches with unique features and principles, but a shared characteristic to operate with real, authentic-like problems aiming to bridge the gap between the theoretical knowledge and real hands-on problems (about PBL and CBL in the context of life sciences, see e.g. Alchin & Allen, 2017). Utilizing case-based texts for learning has been particularly popular in several areas of professional education, such as in medicine, business, law, and engineering (Boshuizen et al., 2020; Williams, 1992).

Although previous studies have provided interesting insights into reasoning of cases (see e.g. Boshuizen, van de Wiel, & Schmidt, 2012), research focusing on the processes by which participants use the case description text while coming to a solution, is scarce. Eye tracking offers a suitable method for investigating that since there is a close connection between the direction of human gaze and the focus of attention (regarding the widely-accepted eye –mind hypothesis, see Just & Carpenter, 1980).

Eye movements in investigating professional development in life sciences

Eye-tracking provides interesting insights in investigating the development of expertise in various contexts. Especially the area of visual expertise has been widely studied, with either static visual stimuli, such as gross anatomical images (Zumwalt, Iyer, Ghebremichael, Frustace & Flannery, 2015), microscopic images (Jaarsma, Jarodzka, Nap, van Merriënboer & Boshuizen, 2014), radiology images (van der Gijp et al., 2017), or graphical data (Harsh et al., 2019), just to mention a few examples. Also processing dynamic visual stimuli has been increasingly studied, such as with fish locomotion patterns (Jarodzka, Schreiter, Gerjerts & van Gog, 2010) and patient video cases (Jarodzka et al., 2012). Eye-tracking research has shown that attention allocation is often influenced by expertise (Reingold & Sheridan, 2011). In comprehension of visualizations, experts seem to have shorter fixation durations, more fixations on task-relevant areas, and less fixations on task-redundant areas compared to non-experts (Gegenfurtner, Lehtinen & Säljö, 2011).

Despite large number of studies concerning expertise in comprehension of visualizations, eye-tracking studies using domain-specific, relevant texts as stimuli seem to be scarce. However, processing various kinds of texts, such as journal articles, records, prescriptions, and product descriptions, is an essential part of life science experts' tasks, which encouraged us to focus on written cases in our studies. In their future work, experts need to be able to effectively differentiate the important substance from competing noise when operating with complex written material. What is known from reading research, is that the typical eye movement pattern in reading is one where the reader makes a sequence of left to right eye movements from one word to another in a way that most words are fixated at least once (Kaakinen & Hyönä, 2019). Because of the close link between where the eyes are gazing and what the mind is engaged with (eye-mind hypothesis, see Just & Carpenter, 1980), readers' eye fixation patterns can be used to investigate the various, ongoing mental processes during reading. Previous research has demonstrated, for example, that longer fixations might reflect difficulties in processing (Kaakinen & Hyönä, 2019; Rayner, 1998; Rayner & Slattery, 2009). Moreover, skilled readers' fixations are briefer than those of less skilled readers, indicating that fixation duration is a successful predictor of reading comprehension (Underwood, Hubbard, & Wilkinson, 1990). Additionally, highly important sentences have been found to attract more visual attention than those that are less important (Hyönä & Niemi, 1990). Thus, attraction of visual attention might be a sign of (high) experienced relevancy to the reader.

Although research utilizing eye tracking in examining expertise in processing text cases is scarce, there are several studies concerning case processing among participants with different levels of expertise. According to previous research literature, novices' and experts', regardless of discipline, processing of information differs remarkably (Chi, Feltovich & Glaser, 1981) and experts' knowledge structures have several advantages over that of novices. One of the main underlying mechanisms of the expertise development process is the increasing sophistication of cognitive schemas, which results that experts are able to to identify, store, and retrieve large meaningful chunks of domain-specific information (Kalyuga, Rikers & Paas, 2012). Experts tend to seek meaningful information to the problem at hand, whereas novices are easily sidetracked toward superficial and often irrelevant material (Etringer, Hillerbrand & Claiborn, 1995; Södervik, Vilppu, Österholm & Mikkilä-Erdmann, 2017).

In this chapter, we present results from two example studies utilizing eye-tracking in the investigation of expertise development in the context of life sciences. In the first study (Study 1), medical students’ and residents’ processing of two, routine and non-routine, written patient cases was investigated via eye-movements, stimulated recall interviews and written tasks. In the second study (Study 2), medical students' processing of a non-routine patient case text was investigated via eye movements and written tasks to explore whether there are differences among students in their processes. Successful solving of these case tasks required understanding and more or less adapting of basic biological background knowledge. Therefore, students’ biomedical knowledge particularly related to their understanding of anatomy and physiology of human cardiovascular system was measured and compared with their success in case tasks utilizing a longitudinal design.

Study 1: Examining the effect of the level of expertise on case processing

The first study example investigates how the level of expertise influences processing and solving patient cases on cardiovascular medicine (Vilppu, Mikkilä-Erdmann, Södervik & Österholm-Matikainen, 2017). Relative novices, third-year medical students (n = 39) and more experienced residents (n = 13) read two patient cases of different difficulty level. The first, routine patient case concerned cardiac failure, and represented a typical textbook example of the condition. The second, non-routine patient case about pulmonary embolus was more demanding, since it did not illustrate a prototypical manifestation of the disease (see e.g. Charlin et al., 2007) and thus, required more adaptivity. Solving both cases required understanding the pathophysiology underlying these conditions as well as adapting basic biological background knowledge concerning the central cardiovascular system, a topic that was familiar for the students from their previous studies. Both cases were structured to depict a patient encounter in a health care center, and thus, they were divided into three phases: anamnesis (i.e. medical history of the patient), status, and examination results from laboratory tests. All the information in patient case text was given in written form (no images), and particular terminology was not used. Additionally, it was not necessary to remember information like reference values or details of the case, since the text also included some interpretation of the results.

Both patient cases included semantically different sentences: key sentences that were essential for solving the case, supplementary sentences that complemented the key sentences and helped to rule out incorrect diagnoses, and irrelevant sentences that were unimportant or contained misleading information concerning the patient case. The case texts were divided into three pages (anamnesis, status, and examination results), and the participants were not to go back and forth, but to proceed in the given order. After each textual slide, a question slide followed, in which the participants were asked to write the most essential symptoms / findings, and give a (working) diagnosis. By dividing the text reading in three phases we wanted optimize the timing of information and limit the amount of cognitive load, which has been a problem in case-based teaching where all the available information is given at once (Kester, Kirschner, van Merrienboer & Baumer, 2001; Kirschner, 2002). During the text reading, the participants' eye movements were recorded. After the second case, a stimulated recall interview was conducted, in which the eye-tracking data was reviewed with the participants to get explanations for issues of interests, such as longer fixations. The purpose of the stimulated recall interview and written tasks between the text slides were to supplement and explain the observed eye movement events, since examining complex cognitive processes requires complementary measures to eye tracking (see Hyönä 2010).

The data analysis consisted of digitizing and scoring the diagnoses, and analyzing the eye tracking metrics: total visit duration per slide (Vilppu et al., 2017) and total dwell time in sentence-by-sentence analysis (Södervik et al., 2017). Each slide, each key sentence and each irrelevant sentence were defined as an area of interest (AOI). Supplementary sentences were excluded from the analyses, since we were more interested about the division of visual attention between the key and irrelevant sentences, and based on earlier research (Hyönä & Niemi, 1990), hypothesized that key sentences would receive more visual attention .

The results indicated that the residents as more experienced actors, were highly efficient case solvers. Their expertise was shown in both the accuracy of the diagnoses and remarkably faster processing times compared to the students in both cases (Vilppu et al., 2017). From the viewpoint of knowledge integration (e.g. Boshuizen & Schmidt, 2018), macro-concepts that enable effective retrieval of large amount of information, and thus faster problem solving compared to students, can explain the residents' superiority. Students' clinical processing, on the other hand, is slower since they must consciously activate their biomedical knowledge, which is more time-consuming compared to more experienced physicians who have access to ready-made structures (Schmidt & Boshuizen, 1993). However, also most of the students (90 %) reached the correct diagnosis in the first, routine, case, but only under half (44 %) in the second, non-routine, case. We will now take a closer look on the analyses of the latter case to see what differs in the processing of participants with differing expertise levels.

The residents were able to give a correct diagnosis of the non-routine case already after reading the first page, anamnesis (Vilppu et al., 2017; Södervik et al., 2017). We suggest this is an indication of the early identification of relevant hypotheses, which is a typical feature of expert behavior in medicine (e.g. Charlin et al., 2007). We believe that some features of the text in the first page triggered script activation, which guided residents' efficient problem solving already from the beginning (Boshuizen & Schmidt, 2018). A closer look to the sentence-by-sentence inspection confirmed this suggestion: the residents read the first key sentence of the case ('The patient is recuperating from knee surgery'), relatively longer compared to the students, although generally residents were remarkably faster readers (see Södervik et al., 2017). It seems that this first key sentence and particularly, a macro-concept "knee surgery" may have activated script(s) in residents' knowledge networks, a finding that was also supported by stimulated recall interviews (see Södervik et al., 2017).

An interesting finding in comparing the students' and the residents' processing was the different processing patterns they demonstrated: the residents' processing time decreased after the first slide (i.e. after reaching the correct solution), whereas all students', regardless of their success in the task, showed an opposite pattern by increasing reading times toward to end of the case (Vilppu et al., 2017). However, the residents and students, who succeeded better in the case task focused more on irrelevant than relevant sentences on the second (status) page (Södervik et al., 2017). This might be due to residents' and better-succeeding students' critical awareness of the fact that sticking to the first hypothesis could be fatal: physicians are taught to systematically test their hypotheses in a script-verification process, which aims at determining whether (any of) the activated script(s) adequately fits the clinical findings until all information is received (see e.g. Charlin et al., 2007). It might be that residents were efficiently checking for excluding criteria concerning their initial diagnosis in the following slides, whereas students were continuing a more indiscriminate search for information.

Study 2: Students' processing of a non-routine case and its relationship to the level of their basic biological knowledge

In our second study example, we focus on comparing the processing of non-routine case task between the students who gave a correct solution (n = 15, 45 %) and students who were unable to reach the correct answer (n = 18, 55 %) (Södervik et al., 2017). In this examination, the case task was the same as the second, more difficult and not prototypical case described in the first study example. In addition, the materials and methods were the same, but supplemented with measurements concerning the level of biomedical knowledge (entrance exam scores, written assignments during first and second study year).

Overall, the students with a correct diagnosis read the case faster than the other group. This supports the previously reported finding that overall reading time correlates positively with experienced text difficulty (e.g. Rayner, 1998). However, the difference was statistically significant only in the last slide, which the students with incorrect diagnoses read longer. Those students also reported more statistically more irrelevant aspects in the written, open-ended question concerning the most essential symptoms and findings after the last slide, whereas the students with a correct diagnosis reported a higher number relevant aspects after reading the last slide (Södervik et al., 2017). Thus, the successful students had greater capacity to distinguish between relevant and irrelevant information. When the student groups' development of biomedical knowledge was compared, we yielded some interesting findings: a total of 11/16 (69 %) of those students who had misconceptions related to basic anatomy and physiology of human cardiovascular system in their 1st or 2nd study year were not able to solve the case successfully in their 3rd study year. In contrast, of those who had scientific model of basic biology in preceding study years, a total of 9/15 (60 %) solved the case correctly (Södervik et al., 2019).

Thus, the quality of biomedical knowledge seems, to at least some extent, to be related to the success in sophisticated case tasks. The result is in line with earlier findings according to which basic science or biomedical knowledge provides a foundation for clinical knowledge (Kaufman, Keselman & Patel, 2008; Woods, 2007). This highlights the importance of basic biological background knowledge as a cornerstone of adaptive expertise. Moreover, revisiting the basic sciences in the clinical phase of medical school has proven advantageous in integrating biomedical science into clinical practice (Spencer, Brosenitsch, Levine & Kanter, 2008). According to Spencer at al. (2008), senior medical students seem better able to appreciate the relevance of basic science concepts to clinical medicine after having spent time on clinical wards, and they often wish they had paid more attention during the first years of basic science courses. Further, as expertise develops in a cumulative manner (Ericsson, 2016), the initial gap between students with weaker and stronger biological background knowledge might even become wider during studies if the problems can not be tackled via instruction.

Educational and methodological implications for higher education

During the last decades, several studies have aimed to understand how university students acquire a high level of competence on their way to achieving expertise in different fields. During this journey, the students need to develop adequate knowledge structures, i.e. to obtain large amount of conceptual knowledge and organise this knowledge to be meaningfully accessible and usable in real-life problem-solving situations. Therefore, teachers as well as learning researchers have begun to focus on adaptive expertise as an important cognitive capacity to understand and promote in an increasingly complex, knowledge-intensive, and fast-changing world (Bransford et al., 2000). Boshuizen and Schmidt (2018, 61) highlight that during the early phases of the development of expertise, in a stage when knowledge accretion and validation take place, 'students should be given ample opportunity to test the knowledge they have acquired for its consistency and connectedness, to correct concepts and their connections and to fill the gaps they have detected'. This process benefits from different learning activities that simulate reasoning processes required later. Learning by cases could provide a beneficial possibility to practice using of theoretical knowledge and solving of authentic-like problems already in the early phases of studies (Boshuizen & Schmidt, 2018). To tap into this phenomenon, this chapter presented results from two earlier studies in which processing of text-based case tasks were investigated utilizing eye-tracking methodology in life science context.

Eye-tracking data revealed interesting aspects related to participants' reasoning processes that can have implications for advancing education in higher education. Firstly, eye movements of more-experienced actors showed that script activation could be detectable from the eye movements as relatively longer visit duration related to those particular text parts. This notion was supported also by the stimulated recall interviews accomplished after reading the case, where several participants of the experienced group explained that this (medical operation) was a critical point, where 'they could get the details to fit together' for script activation. The finding has both methodological and pedagogical implications: Firstly, it proves that eye tracking is an excellent methodology to study reasoning processes of text-based cases. Secondly, it supports earlier findings, according to which supporting the students in developing macro-concepts and scripts relevant for the particular discipline, would be of utmost importance in higher education (Boshuizen & Schmidt, 2008; Boshuizen et al., 2020). However, based on our findings, training of routine tasks may well foster students' efficiency in problem-solving, but does not necessarily prepare them to become flexible problem-solvers ready for unexpected and non-routine situations.

Thus, complexity, structure and difficulty level should vary, when designing learning activities based on cases that are to support the development of adaptive expertise. Bohle Carbonell and colleagues' (2014) review of adaptive expertise studies noted that training activities that: a) stimulate learners to confront with novel situations and new tasks b) allow learners to make errors and get feedback (it is important that a link is made between the errors and the to-be-learned knowledge) and c) to try out different solutions benefit the creation of a flexible knowledge base associated with adaptive expertise. Thus, cases as instructional methods for promoting the active knowledge building should be designed to support students to become aware of their prior knowledge and reveal to learners the outcomes of their choices to help learners' self-regulation (Södervik, Mikkilä-Erdmann & Chi, 2019; Vilppu, Mikkilä-Erdmann & Ahopelto, 2013). When students' processing starts to operate utilizing macro-concepts instead of large amount of single details, that again enhances their self-regulation during processing, since monitoring of reasoning on integrated concepts in a network requires less control than monitoring of reasoning on detailed concepts (Boshuizen & Schmidt, 2018). Above described learning activities provide individuals with challenges that go beyond their current level of reliable performance—ideally in a learning context that allows immediate feedback and gradual refinement by repetition and intentional improvements (Ericsson, 2014).

Based on previous research, the structure of the scientific as well as the practical knowledge available and taught in the different domains plays a crucial role in the development of macro-concepts and scripts. In their review, Boshuizen and colleagues (2020) noted that theoretical knowledge lays the foundation for developing on macro-concepts and scripts. Our results confirmed this, because script activation seemed to play a role in non-routine case processing (a finding that could be detected from eye movements of residents) and additionally, the level and quality of students' basic biological knowledge was related to students' success in non-routine case task. These findings lead to pedagogical conclusion that fostering forming of macro-concepts and and scripts and utilizing of them in non-routine problem-solving situations is an aim of utmost importance in higher education. To conclude, based on the studies synthesized in this chapter and several other previous studies, university students would benefit from frequent exposure to authentic case tasks aligning theory and practice.

CONCLUSIONS

Eye-tracking method has great potential in assessing growing expert performance with written texts as stimuli. Our studies showed that the more experienced actors required less time and fewer fixations to produce more accurate answers compared to the students. In addition, the students appeared to demonstrate different reading patterns compared to more experienced actors. For the latter group, making a decision regarding the solution decreased their reading time of the following text, whereas the students increased their reading time toward the end of the case.

The most important finding from our studies is related to the processing of non-routine case task, which revealed that the script activation may be detectable from the eye movements considering that more experienced actors read longer the sentence including a relevant macro-concept and solved the case correctly based on the information provided in this part of the text. In spite of the fact that experienced actors gave a correct working hypothesis already in the beginning of text reading process, both them as well as better-succeeding students focused even more on irrelevant text parts after the first working hypothesis. This was interpreted to indicate about the script-verification process, which is suggested to be relevant in adaptive problem-solving, where sticking to the first working hypothesis without all the information available might lead into false solution. Lastly, since students' level and quality of basic biological knowledge was related to their success in case task, where the basic biological knowledge needed to be applied, it is a necessity to design learning activities that support students' to bridge basic science with authentic problem-solving reasoning. To conclude, repeated processing of domain-relevant cases seems to be important in supporting the development of adaptive expertise in life sciences. This notion should be taken seriously in spite of the fact that study programs always struggle with allocation of time to theory and practice.

To conclude, facilitating the development of adaptive expertise is currently seen as vital aim in life sciences in higher education. Human society unquestionably needs experts, who are able to use their knowledge structures flexibly and adaptively to protective well-being at Earth, even when unforeseen global catastrophes and crisis threaten it. Continuous changes mean that we do not know today the specific set of skills and knowledge that will be necessary for future experts to succeed and thrive in the decades to come, but we do know that it is imperative for life science experts to be able to use their knowledge and skills adaptively to face the challenges of fast paced requirements. Latest examples, such as coronavirus (Covid-19) pandemic and climate change, have shown that preparing to unexpected is a crucial skill that future experts will need when solving such wicked problems. Methods that enable investigating learning online, at processing-level, such as eye tracking, have the potential to reveal important insight into learning via different-level cases as well as obstacles that students experience at stages of development toward expertise. These findings should have implications on instruction in higher education in rapidly changing world, where adaptability is an increasingly important skill for future experts.

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