Chapter 9
Case Processing in the Development of Expertise in Life Sciences-What Can Eye Movements Reveal?

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Introduction

The quality of life science experts' work contributes strongly to the well-being of human society and the whole globe on numerous levels; 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 pandemics of severe infections, antibiotic resistance, biodiversity loss and climate change, that will require innovative ways of reasoning, as well as the ability to use knowledge and skills adaptively in unforeseen and sometimes even adverse contexts. In addition, frequent changes in current work environments as well as a rapidly changing society call for experts who possess the required domain expertise, can quickly overcome changes, and are able to update their competencies (Bohle Carbonell et al., 2014). To achieve this, future experts need reasoning skills that exceed 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 innovativeness, although their 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

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(Bertram et al., 2013). Therefore, supporting the development of expertise at universities requires meaningful instructional operations that support the development of reasoning skills relevant to a particular discipline. Currently, it has been suggested that the development of expertise requires 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 a large amount of concepts that are relevant to a 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, the formation of so called macro-concepts (for example biodiversity, evolution or photosynthesis), in which knowledge networks are organized so that large amounts of lower-level conceptual details are clustered under higher-order concepts. Knowledge integration enables experts to, for example, effectively retrieve large amounts of information from their knowledge network, because of direct links that can be made between the first and last concepts in a certain line of reasoning, skipping some intermediate details (Boshuizen & Schmidt, 2018). This type of processing 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 of 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 et al., 2000). In medicine, for example, it has been well established that this phase in the development of expertise leads the students not actively using much basic biological knowledge while reasoning, but operating more actively with macro-concepts and generating certain 'fast tracks' for reasoning, i.e. scripts (Boshuizen & Schmidt, 2018). However, the use of 'fast tracks' and routines is a two-edged sword: on the one hand, it makes routine cognitive processing more effective, enabling us to exceed the limits of our cognitive capacity, but on the other hand, it may impede 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 et al., 1997). Thus, these tendencies ought to be taken into account in designing instruction at universities, because unless they are actively resisted, the education system may continue to produce graduates who possess expert knowledge, but cannot reliably access or apply it innovatively in novel situations (Gube & Lajoie, 2020; Hatano & Oura, 2003; Sternberg, 2003).

The findings mentioned above have led to the study of qualitatively different types of expertise: 'routine' and 'adaptive' expertise (Hatano & Inagaki, 1986). Research has noted that while routine experts continue improving their fluency and efficacy over time, adaptive experts possess 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 et al., 2005). Thus, adaptive expertise is considered a fundamentally different conception of professionalism instead of 'the next step' after routine expertise. However, despite broad agreement that adaptive expertise is a worthy goal of university education (Hammerness et al., 2005) relatively little is currently known about the adaptive expertise capabilities of university students, nor about how 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 on 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 life sciences, including medicine. In these studies, an eye-tracking method was used to investigate 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 largely domain-specific, meaning that experts in a specific domain do not develop problem-solving skills that can 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 effectively support learning, especially in the early stages of education, when learners have to perform reasoning related to conceptual knowledge, and when real hands-on problems can still be overwhelming (see e.g. Boshuizen & Schmidt, 2018; Boshuizen et al., 2020).

Case tasks can be defined as descriptions of specific events or problems that are drawn from the real world of professional practice (Ramaekers et al., 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 mental activities and processes similar to those used in real work life (Brown et al., 1989). In real-life situations, for example, not all the required information is typically available at the beginning of the problem-solving situation, but becomes available step by step, requiring the evaluation of information during the action. This process relates to a script-verification process in which the expert attempts to determine whether any of the activated scripts adequately fits the findings, until all available information is received (see e.g. Charlin et al., 2007). Even more importantly, in real settings experts must address complex and multifaceted cases, and should therefore include contingencies, complexities and dilemmas requiring differentiating of relevant substance and aspects from less relevant noise. Effective case processing and knowledge restructuring are key concepts of expertise development (see Boshuizen et al., 2020), and thus learners' knowledge structures must become organized in a way that enables the effective processing of information.

Most of the research related to cognitive adaptation during expertise development has been conducted in medical domains (see e.g. Boshuizen & Schmidt, 1992; de Bruin et al., 2005; Feltovich & Barrows, 1984; Kuipers & Kassirer, 1984; Patel et al., 1989; Schmidt & Boshuizen, 1993; Schmidt & Rikers, 2007). However, based on a recent extensive review related to the theory of knowledge restructuring through case processing, similar cognitive processes and transitions on the path to expertise also seem to be relevant across domains (Boshuizen et al., 2020). Therefore, although also most of the studies related to the role of learning by cases during the development of expertise have been conducted in the medical domain (including the two example studies presented in this chapter), the findings can be somewhat generalized to other scientific fields too. There is a long history of using various problem-analysis methods in medical 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.

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

Although previous studies have provided interesting insights into the reasoning of cases (see e.g. Boshuizen et al., 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 these processes, 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 into the development of expertise in various contexts. The area of visual expertise in particular has been widely studied, using static visual stimuli, such as gross anatomical images (Zumwalt et al., 2015), microscopic images (Jaarsma et al., 2014), radiology images (van der Gijp et al., 2017) or graphical data (Harsh et al., 2019), just to mention a few examples. The processing of dynamic visual stimuli has increasingly been studied as well, such as with fish locomotion patterns (Jarodzka et al., 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 exhibit shorter fixation durations, more fixations on task-relevant areas and fewer fixations on task-redundant areas compared to non-experts (Gegenfurtner et al., 2011).

Despite the large number of studies concerning expertise in comprehension of visualizations, eye-tracking studies using domain-specific, relevant texts as stimuli are scarce. However, processing various texts, such as journal articles, records, prescriptions and product descriptions, is an essential task for life science experts. This 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 for the reader to make a sequence of left to right eye movements from one word to another, such that most words are fixated on 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 of 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 et al., 1990). Additionally, highly important sentences have been found to attract greater 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 to examine 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' processing of information differ remarkably, regardless of discipline (Chi et al., 1981), and experts' knowledge structures have several advantages over those of novices. One of the main underlying mechanisms of the expertise development process is the increasing sophistication of cognitive schemas, which means that experts are able to identify, store and retrieve large meaningful chunks of domain-specific information (Kalyuga et al., 2012). Experts tend to seek information meaningful to the problem at hand, whereas novices are easily sidetracked towards superficial and often irrelevant material (Etringer et al., 1995; Södervik et al., 2017).

In this chapter, we present results from two example studies that use eye-tracking to investigate expertise development in the context of life sciences. In the first study (Study 1), medical students' and residents' processing of two written patient cases, routine and non-routine, 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 using eye movements and written tasks to explore whether there were differences among the students' processes. Successful solving of these case tasks required understanding and greater or less adaptation of basic biological background knowledge. Therefore, students' biomedical knowledge, particularly that 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 the processing and solving of patient cases in cardiovascular medicine (Vilppu et al., 2017). Relative novices, third-year medical students ($n = 39$) and more experienced residents ($n = 13$) read two patient cases of different difficulty levels. 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 greater adaptivity. Solving both cases required an understanding of the pathophysiology underlying these conditions, as well as the ability to adapt basic biological background knowledge concerning the central cardiovascular system, a topic that was familiar to the students from their previous studies. Both cases were structured to depict a patient encounter in a health care centre, 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 the patient case texts was provided in written form (no images), and specific terminology was not used. Additionally, it was not necessary to remember information such as 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 to 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 note the most essential symptoms/findings, and provide a (working) diagnosis. By dividing the text reading into three phases, we sought to optimize the timing of information and limit the cognitive load, which has been a problem in case-based teaching where all the available information is given at once (Kester et al., 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 obtain explanations for issues of interests, such as longer fixations. The purpose of the stimulated recall interview and written tasks between the text slides was 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 was 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, being more experienced actors, were highly efficient case solvers. Their expertise was shown in both the accuracy of the diagnoses and remarkably shorter processing times compared to the students in both cases (Vilppu et al., 2017). From the viewpoint of knowledge integration (e.g. Boshuizen & Schmidt, 2018), the residents' superiority can be explained by their use of macro-concepts that enable the effective retrieval of large amounts of information, and thus faster problem-solving compared to students. On the other hand, students' clinical processing 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, most of the students (90%) also 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 at the analyses of the latter case to see what differs in the processing of participants with differing expertise levels.

The residents were already able to diagnose the non-routine case correctly after reading the first page, anamnesis (Vilppu et al., 2017; Södervik et al., 2017). We suggest that this indicates the early identification of relevant hypotheses, which is a typical feature of expert behaviour 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 right from the beginning (Boshuizen & Schmidt, 2018). A closer look at 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 than the students, although residents were generally remarkably faster readers (see Södervik et al., 2017). It seems that this first key sentence, and particularly the macro-concept of '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 the opposite pattern by increasing reading times towards the end of the case (Vilppu et al., 2017). However, the residents and the 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 to determine 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 focused on comparing the processing of a 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 non-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 years).

Overall, the students who supplied 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 irrelevant aspects in the written, open-ended question concerning the most essential symptoms and findings after the last slide, whereas the students who diagnosed correctly reported a higher number of relevant aspects after reading the last slide (Södervik et al., 2017). Thus, the successful students had a 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 held 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 a scientific model of basic biology in the 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 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 et al., 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 et al., 2008). According to Spencer et 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 their studies if the problems cannot be tackled via instruction.

Educational and Methodological Implications for Higher Education

Over the last decades, several studies have aimed to explicate 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 amounts of conceptual knowledge and organize 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, p. 61) highlight that, during the early phases of the development of expertise, at 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 various learning activities that simulate the reasoning processes required later. Learning by cases could provide a beneficial opportunity to practice using theoretical knowledge and solving authentic-like problems even 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 using eye-tracking methodology in a life science context.

Eye-tracking data revealed interesting aspects of participants’ reasoning processes that can have implications for improving higher education. Firstly, eye movements of more experienced actors showed that script activation could be detected from the eye movements as relatively longer visit durations to those particular text parts. This notion was supported by the stimulated recall interviews after the case had been read, during which 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 the reasoning processes of text-based cases. Secondly, it supports earlier findings, according to which supporting the students in developing macro-concepts and scripts relevant to 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 who are ready to deal with 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 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 knowledge to be learned) and (c) allow learners to try out different solutions support the creation of a flexible knowledge base associated with adaptive expertise. Thus, cases as instructional methods to promote 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 the learners' self-regulation (Södervik et al., 2019; Vilppu et al., 2013). When students' processing starts to operate with macro-concepts instead of a large number 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). The learning activities described above 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 through repetition and intentional improvement (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 the eye movements of residents), and additionally the level and quality of students' basic biological knowledge was related to students' success in non-routine case tasks. These findings lead to the pedagogical conclusion that fostering forming of macro-concepts and scripts, and using them in non-routine problem-solving situations, is an aim of utmost importance in higher education. Based on the studies synthesized in this chapter and several other previous studies, university students would benefit from frequent exposure to authentic case tasks that align theory and practice.

Conclusions

Eye-tracking method shows 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 towards the end of the case.

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

To conclude, facilitating the development of adaptive expertise is a 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 protect well-being on 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 rapidly changing requirements. Recent examples, such as the coronavirus (Covid-19) pandemic and climate change, have shown that preparing for the unexpected is a crucial skill that future experts will need to solve such wicked problems. Methods that enable investigating learning online at the processing level, such as eye tracking, have the potential to reveal important insights into learning via different-level cases, as well as the obstacles that students experience at various stages of development towards expertise. These findings should have implications on instruction in higher education in a rapidly changing world, where adaptability is an increasingly important skill for future experts.

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