The role of prior knowledge and students' perceptions in learning of biomedical sciences

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Abstract

The present study investigates whether medical students' prior knowledge and perceptions about basic biomedical sciences predict learning of these topics at early phases of the medical education. Participants (N = 115) were first year medical students at University of Turku (Finland). The data consisted of a student perception questionnaire, entrance examination results, and the examination scores of the first year preclinical courses. Compared to the students having only education at the upper secondary school level (n = 58), the students with prior university studies in sciences (n = 57) performed better in the first year course examinations. Out of the four entrance examination sub-tests, only the sub-test in biology predicted performance in the first year course examinations. In terms of students' perceptions, the students rated the courses that dealt with the human body on microscopic or molecular level the least useful and the most difficult. Yet, the perception of usefulness had no effect on examination performance. The results emphasise the role prior knowledge especially in biology has for learning of medicine. Furthermore, the first year medical students seem to value topics that are more closely related to their everyday experiences and, therefore, perhaps less abstract. The courses on cellular and molecular levels were rated notably low with regard to usefulness. The relevance of cellular and molecular biology to medical profession should be communicated more clearly to the students. Furthermore, basic science topics may benefit from a more integrative pedagogical approach in which the biomedical concepts are conceptualised in diagnostic practice.

Keywords

Biomedical sciences – prior knowledge – student perceptions – student selection

Introduction

It is widely accepted that developing medical expertise requires deep integration of biomedical and clinical knowledge [1-4]. However, less is known about how different knowledge bases interact and develop during the early phases of medical education. And although it is widely accepted that relevant prior knowledge facilitates learning of new content, the relevance of different knowledge bases for medical education has been debated for decades by researchers, medical educators and medical students alike [e.g. 5-6]. For example, the curriculum reforms of the last decades have tended to emphasise a more problem-based pedagogy and, therefore, clinical knowledge, although critique has been expressed [7-10]. Furthermore, the latest reforms have incorporated a myriad of new characteristics and non-medical professional competencies such as socio-emotional competences or managerial skills into the curriculum [11-14]. Such skills may appear to be more closely related to clinical work than basic biomedical sciences. This might have an impact on medical students' perceptions of and preferences within the curriculum. Therefore, this study investigates the relationship between medical students' prior knowledge and learning of basic biomedical sciences, and how students perceive the content of first curriculum year of medical school in terms of usefulness for their future learning and profession.

Despite the highly selective entrance requirements and examinations, students enter the medical school with varied prior knowledge. In their review, Ferguson, James and Madely found out that previous academic performance (e.g. A level grades, grade point averages, admission tests) accounted "for 23% of the variance in performance in undergraduate medical training" [15]. However, the predictive power of previous academic performance declines considerably as studies advance [15-16]. Similarly, Ellaway et al. [17] showed that students with backgrounds in the biomedical sciences outperformed their "non-science" peers, but only initially. In addition to prior academic performance, medical schools use a variety of other selection criteria of which entrance examinations or admission tests are perhaps the most widely used due to their apparent objectivity. Furthermore, entrance examinations make it possible to test, and therefore standardise, the medical students' knowledge in areas that are deemed relevant for medical education. The predictive validity of different admission test types has been studied and debated extensively [18]. Indeed, the findings are mixed. For example, according to Lynch et al. [19], the United Kingdom Clinical Aptitude Test (UKCAT) does not predict students' first year performance in medical school. In fact, they found that higher score in the decision analysis task was related to re-sitting final examinations. The corresponding BioMedical Admissions Test (BMAT) seems to predict performance during pre-clinical years [20]. However, most of its predictive validity comes from the "Scientific Knowledge and Applications" section, leaving the "Aptitude and Skills" section insignificant [21]. The results are equally varied when it comes to the admission tests on graduate level. For example, Wilkinson et al. [16] studied the predictive power of the Graduate Australian Medical School admission Test (GAMSAT), which measures reasoning in humanities and social sciences, written communication and reasoning in biological and physical sciences. They found that GAMSAT had a practically non-existent correlation with academic performance in medical school, whereas grade point average had a medium sized correlation coefficient with it. On the other hand, the American counterpart, Medical College Admission Test (MCAT), with sections for verbal reasoning, biological sciences, physical sciences and writing, proved to be a reasonably reliable predictor of performance throughout the medical school [22-23]. Therefore, the nature and the scope of the knowledge and skills that should be required, and tested, from the applicants for medical school is still open for debate. It should be noted that the current study took place in the context of Finnish medical education, which is structurally most similar to the medical education in, for example, the United Kingdom, France, Germany, The Netherlands and Italy. In the United States and in Australian graduate medical schools, a bachelor's degree is an entrance requirement for medical schools. In Finland and many other European countries, medical students enter the medical school after secondary school [24].

In addition to prior knowledge, students' perceptions of basic biomedical sciences play, potentially, a critical role in how the students learn topics that are, traditionally, taught in the preclinical phase. There is a "popular notion that most of basic science knowledge is forgotten shortly after graduation" [25]. Therefore, it is not surprising that both medical students and clinical teachers seem to value clinical knowledge more than basic biomedical sciences, especially when it comes to their future profession. For example, Bhangu, Boutefnouchet, Yong, Abrahams and Joplin [26] studied medical students' attitudes towards anatomy teaching. They found that only 28% of the second year students believed that anatomy courses prepared them appropriately to interpret medical images. Similarly, students occasionally express "a deficit in meaningfulness" [27] with regard to learning of gross anatomy. However, it seems that students and clinical teachers are even more skeptical when it comes to the value of knowledge on cellular and molecular levels [28].

Especially medical biochemistry is often perceived by medical students as irrelevant, overly demanding and difficult [29-31]. Yet, the perceived importance of basic biomedical sciences seems to increase as students enter the clinical work [32-33]. The present study investigates students' perceptions of basic biomedical sciences both in terms of their future studies and profession, and whether the perceptions are related to the learning of these topics.

Research questions

The aim of this study was to investigate a) if students' prior knowledge in science affects their performance during the first year of medical education, b) how the students perceive the first year basic biomedical courses in terms of usefulness for their future studies and profession as well as difficulty, and, c) if the perceived usefulness and difficulty correlate with students' examination performance.

Methods

Sample and context

The voluntary participants (N = 115, 59% of the student cohort) were first year medical students in the University of Turku, Finland. Participation was voluntary and informed consent was obtained from all participants. The study was approved by the Ethics Committee of the University of Turku, Finland.

In Finland, in order to enter the medical faculty, the students must pass a national entrance examination based on the courses in biology, chemistry and physics learned at the upper secondary school level. Medical studies are based on a six years program in medical faculties. Independently of their prior university studies all students start their studies from the beginning of that curriculum. This means that in the same groups there can be recent high school graduates and students with several years of university studies in basic sciences. In our sample, seventy of the participants reported prior university studies, mainly in natural sciences.

The curriculum of the first year studies in the Medical Faculty of Turku University included the following topics: Cell and developmental biology (12 credits), Musculoskeletal system (9 credits), Medical biochemistry and molecular medicine (11 credits), Structure and function of internal organs (13 credits). Medical English (1 credit) and Introduction to medical profession (5 credits) were included in the curriculum as well.

Instruments

Three sorts of data were collected: Entrance examination results, first year examination results and students' perceptions of usefulness and difficulty.

1) Entrance examination was composed of sub-tests in biology, physics, chemistry and of a knowledge application task. The level of the entrance examination corresponded to the courses of the Finnish high school common to all persons in the study. The contents of the knowledge application task's supplementary material "Zoonoses, tissue injury and sorting of infected cells" (11 pages, including 6 figures) was planned so that it, most evidently, was

not well-known, or known not at all, among the applicants. The entrance exam questions were integrated into medical applications and required the ability to integrate and combine biological, physical and chemical approaches. The students were asked to answer multiple choice questions (MCQ) related to this material (18 points). Furthermore, the knowledge application task included two figures and an explanation of a chemical reaction, which were followed by 29 claims that the students had to mark as being true or false (10 points). The task also included 6 MCQs about basic physics (6 points). However, only the sum score of the knowledge application task (34 points) was available for the current analysis. The sub-test for biology (44 points) included 4 open questions (topics related to histology, menstrual cycle, ozone layer and climate, DNA replication and transcription). In one of the tasks the students were asked to fill in missing words (adjectives or substantives) in a text dealing with the effects of sunlight on living organisms. The physics sub-test had five mathematically oriented tasks (36 points) related to radiation, mechanics, electro-magnetism and electricity. The students were provided with a set of equations and constants for this purpose. Finally, in the chemistry sub-test (5 tasks, 35 points) the students were asked to solve chemical reactions and describe chemical phenomena at cellular and human body level.

2) The first year course examination results of Cell and developmental biology, Musculoskeletal system, Biochemistry and molecular medicine, and Structure and function of internal organs. The Cell and developmental biology course examination had forty true/false tasks (e.g. “microsatellites are especially prone to replication errors”), 8 short open questions (e.g. “define miRNA” and “the central characteristics and histological

features of different muscle cell types") and 6 image interpretation tasks (e.g. "what type of epithelium the image represents and where this kind of epithelium can be found?"). The Muscoskeletal system course examination consisted of 36 MCQs of which 14 were related to an image (e.g. "The arrow points at… m. digastricus venter posterior"). Biochemistry and molecular medicine course examination scores included three different exams of which students were able to get 180 points altogether. Sixty points came from true/false questions (e.g. "In the electron transport chain, oxygen functions as the final electron recipient") and 120 points from short open (e.g. "define iPSC (induced pluripotent stem cell)") and essay questions (e.g. "Urea cycle, function, significance and disorders"). Finally, the Structure and function of internal organs course examination was divided into the following subsections: blood respiration and liquid balance (30 points), digestion and nutrition (40 points), endocrinology (40 points). Each subsection consisted mainly of short definition tasks and open questions.

3) A questionnaire about students' perceptions

The students were asked to rate (on a scale from 1 = "useless" to 7 = "very useful") all the above-mentioned courses in terms of their usefulness for their future studies (US), usefulness for their future profession (UP), and difficulty (on a scale from 1 = "easy" to 7 = "very demanding"). Students were also asked if they had prior university studies and if so, in which subject and with how many ECTS (European Credit Transfer and Accumulation System) credits (1 ECTS credit entails 25-30 hours of study time).

Procedure

The entrance and course examination scores were obtained from the electronic study register, but only after receiving the ethical clearance from the Ethics Committee and the informed consent from each participant. The paper-pencil questionnaire was administered during the last lessons of the first year of medical school.

Analysis

The analysis was carried out in IBM SPSS statistics software. To examine the role of prior knowledge, students were divided into two groups based on whether they had more than 15 ECTS credits of prior university studies in basic, or natural, sciences (N = 57: chemistry n = 26, biochemistry n =16, physics n = 6, biology n = 4, medicine n = 5) or not (N = 58, no prior university studies n = 43, studies in humanities n = 11, or less than 15 ECTS in science n = 4). The requirement of 15 ECTS was deemed appropriate to sort out students who had only taken one or two courses in basic sciences, after which the mean number of ECTS in the science group was 60.2 (SD = 52.7, min = 15, max = 360). The number of participants varies slightly in the following analyses due to occasional missing data (e.g. course examination score) and removal of outliers by using boxplots. The effect of prior science studies on examination performance was studied with multivariate analysis of variance (MANOVA). The relationship between the entrance examination and course examination was investigated with stepwise regression analysis. Furthermore, the relationship between students' course examination scores and perceptions were investigated by analysing the corresponding Pearson correlations.

Results

Prior knowledge in science and course examination performance during the first year of medical education

On average, students with prior studies in science achieved higher scores in all four course examinations (Table 1). The MANOVA showed that prior science studies have a significant effect on students first year examination performance, Pillais's Trace $V = 0.12$, F (4, 91) = 2.98, $p = .023$. Furthermore, the separate univariate ANOVAs revealed a statistically significant effect between prior science studies and Muscoskeletal system course examination F (1, 94) = 12.15, $p = .001$.

Table 1 Means of course examination scores for students with and without prior science studies

Prior science studies		Cell and developmental biology	Musculoskeletal system	Biochemistry and molecular medicine	Structure and function of internal organs
No	Mean	64.0	16.8	107.7	87.1
	SD	7.9	6.7	26.4	9.3
	N	49	50	50	49
Yes	Mean	65.5	21.2	116.8	90.3
	SD	8.3	5.0	24.4	8.1
	N	49	49	49	48
Total	Mean	64.7	19.0	112.2	88.7

SD	8.1	6.2	25.7	8.8
N	98	99	99	97

In the stepwise regression analysis of entrance and course examination results, only the biology sub-test of the entrance examination emerged as a significant predictor for three course examination scores, namely, Cell and developmental biology [$F(1,86) = 7.57$, $p = .07$, $R^2 = .08$], Biochemistry and molecular medicine [$F(1,87) = 8.21$, $p = .005$, $R^2 = .09$] and Structure and function of internal organs [$F(1,85) = 19.21$, $p = .001$, $R^2 = .18$]. Correspondingly, the statistically significant correlations between the biology sub-test and the four biomedical courses ranged from modest to medium effect: Cell and developmental biology ($r = .28$, $p = .007$), Biochemistry and molecular medicine ($r = .29$, $p = .005$), Structure and function of internal organs ($r = .43$, $p = .001$).

Students' perceptions of the first year courses in terms of usefulness and difficulty

Of the first year courses in the medical faculty, the students reported the course on Musculoskeletal system as the most useful both for their future studies and future profession. The courses on Cell and developmental biology and Biochemistry and molecular medicine were rated as the least useful on both the usefulness for future studies (US) and usefulness for future profession (UP) scales (Tables 2 and 3). Interestingly, these courses had even lower ratings than the Medical English course. However, the both courses were given higher US than UP ratings, indicating that, to some extent, the students do realise the role these topics play in developing the medical knowledge base. Furthermore, the course on Biochemistry and molecular medicine was rated as the most difficult and the course on Structure and function of internal organs as the easiest course (excluding Medical English, Table 4) among those studied. It should be noted that students with prior studies in science did not rate the basic biomedical courses differently from students without science background.

Table 2 Perceived usefulness for future studies (scale 1-7, *N* = 115)

	Minimum	Maximum	Mean	*SD*
Cell and developmental biology	1	7	4.8	1.2
Musculoskeletal system	4	7	6.4	0.9
Biochemistry and molecular medicine	1	7	5.0	1.2
Structure and function of internal organs	2	7	6.0	1.1
Medical English	2	7	5.7	1.4

Table 3 Perceived usefulness for future profession (scale 1-7, *N* = 115)

	Minimum	Maximum	Mean	*SD*
Cell and developmental biology	1	7	3.4	1.3
Musculoskeletal system	2	7	6.3	1.0

Biochemistry and molecular medicine	1	7	3.9	1.4
Structure and function of internal organs	2	7	6.0	1.2
Medical English	2	7	5.1	1.5

Table 4 Perceived difficulty (scale 1-7, *N* = 115)

	Minimum	Maximum	Mean	*SD*
Cell and developmental biology (*N* = 114)	2	6	4.1	1.1
Musculoskeletal system	3	7	4.9	1.0
Biochemistry and molecular medicine	2	7	5.1	1.1
Structure and function of internal organs	2	6	3.8	1.0
Medical English	1	5	2.3	1.1

The relation of perceived usefulness, difficulty and students´ examination performance

Neither US nor UP correlated significantly with the course examination scores (Tables 5 and 6). The only statistically significant, but small, correlation was found between the course on Biochemistry and molecular medicine and its corresponding US and UP. The course-specific difficulty ratings correlated significantly both with the Cell and developmental biology and Biochemistry and molecular medicine scores (Table 7). The students who perceived the Cell and developmental biology course to be demanding performed worse also in the Biochemistry and molecular medicine and Structure and function of internal organs examinations. Similarly, the difficulty rating of Biochemistry and molecular medicine course correlated negatively with Cell and developmental biology and Structure and function of internal organs examination scores. This is understandable considering the overlap in the course syllabi. For example, the Cell and developmental biology course deals with the basic histological structures and major functions of the constitutive cells, which are closely related to the structure and function of internal organs.

Table 5 Pearson correlations between the course examination scores and perceived usefulness for future studies (US), $N = 113$

	1	2	3	4	5	6	7	8
1. Cell and developmental biology	-							
2. Musculoskeletal system	.32**	-						
3. Biochemistry and molecular medicine	.63**	.59**	-					
4. Structure and function of internal organs	.59**	.58**	.69**	-				
5. Cell and developmental biology, US	.10	.11	.11	.03	-			
6. Musculoskeletal system, US	-.09	.17	.11	.08	.35**	-		
7. Biochemistry and molecular medicine, US	.14	.15	.28**	.12	.62**	.27**	-	
8. Structure and function of internal organs, US	-.03	.21*	.13	.11	.38**	.67**	.38**	-

**. Correlation is significant at the .01 level (2-tailed).
*. Correlation is significant at the .05 level (2-tailed).

Table 6 Pearson correlations between the course examination scores and perceived usefulness for future profession (UP), *N* = 113

	1	2	3	4	5	6	7	8
1. Cell and developmental biology	-							
2. Musculoskeletal system	.32**	-						
3. Biochemistry and molecular medicine	.63**	.59**	-					
4. Structure and function of internal organs	.59**	.58**	.69**	-				
5. Cell and developmental biology, UP	.12	.18*	.15	.11	-			
6. Musculoskeletal system, UP	-.09	.12	.08	.09	.33**	-		
7. Biochemistry and molecular medicine, UP	.11	.18	.26**	.14	.69**	.41**	-	
8. Structure and function of internal organs, UP	-.05	.20*	.09	.10	.40**	.55**	.33**	-

**. Correlation is significant at the .01 level (2-tailed).

*. Correlation is significant at the .05 level (2-tailed).

Table 7 Pearson correlations between the course examination scores and perceived difficulty (D), *N* = 112

	1	2	3	4	5	6	7	8
1. Cell and developmental biology	-							
2. Musculoskeletal system	.32**	-						
3. Biochemistry and molecular medicine	.63**	.59**	-					
4. Structure and function of internal organs	.59**	.58**	.69**	-				
5. Cell and developmental biology, D	-.44**	.02	-.25**	-.25**	-			
6. Musculoskeletal system, D	.04	-.09	-.01	-.14	.27**	-		
7. Biochemistry and molecular medicine, D	-.28**	-.14	-.31**	-.19*	.30**	.24*	-	
8. Structure and function of internal organs, D	-.07	.13	-.05	-.11	.20*	.40**	.11	-

**. Correlation is significant at the .01 level (2-tailed).
*. Correlation is significant at the .05 level (2-tailed).

Discussion

In comparison to students who had not studied science at university level previously, students with prior university studies in science performed better in the first year course examinations of medical school. However, out of the four sub-tests of the entrance examination, only the biology sub-test correlated with the first year course examination performance. In terms of students' perceptions, the students rated the courses that deal with the human body at microscopic or molecular level the least useful and the most difficult. Yet, the perception of usefulness had little, if any, effect on examination performance. The difficulty ratings correlated negatively with course examination performance.

The results converge with the findings of Ellaway et al. [17]. At least initially, students with prior university studies in science outperform their peers. It is plausible that science studies prepare the students for future learning [34] by enabling the application of prior knowledge and by enhancing the acquisition of novel knowledge [35, 36]. Whether this should be taken into account in the selection criteria of the students is a double-edged sword. On the one hand, students with no prior university studies in science can, demonstrably, succeed equally well in the later stages of medical school and professional life [15-17]. On the other hand, a student cohort could possibly achieve better learning results as a whole if their prior knowledge in sciences was on a higher level. Furthermore, the fact that biology was the only sub-test of the entrance examination that correlated with course examination performance suggests that it should, or could, be favoured in the selection criteria of medical students. However, while the results strengthen the idea that biology is extremely important for learning of medicine, the current study does not disprove the importance of physics or chemistry either. The lack of correlations between other physics and chemistry sub-tests and course examinations could be at least partly due to the limited range of the entrance examination, as only the students who were successful in the entrance examination were part of the study. The variance of scores might therefore have been limited. In fact, there is some evidence that for example physics knowledge can improve diagnostic performance [37]. Yet, the results do emphasise the importance of biology knowledge as it shows statistically significant correlations even in a highly selected group of students.

Furthermore, the current study adds to our knowledge of medical students' perceptions with regards to basic biomedical sciences. In sum, medical students' seem to value topics that are more closely related to our everyday experiences (muscoskeletal system and organs) and, therefore, perhaps less abstract. Nevertheless, it seems that students' perceptions of basic sciences evolve both during their studies and professional life. Custers and Ten Cate [32] showed that medical clerks' attitudes towards basic sciences become more positive as their clerkship advances. Compared to the beginners, advanced clerks were more inclined to agree that it is necessary to learn factual biomedical knowledge first and clinical application later. It is noteworthy that courses on cellular and molecular levels are rated as less useful than, for example, the Medical English course. As Afshar and Han [38] argue, “[a]dvancement of medicine and that of biochemistry are inseparable, and much of modern medicine would not be practiced in the ways, as they are known today, without our understanding of how genetic, pathogenic and environmental factors affect the human body at the biochemical level.” The fact that Biochemistry and molecular medicine course was perceived as the most difficult might, at least partly, explain why it was also perceived as less useful. If one struggles to understand the subject itself, she or he might struggle even more to understand the relevance of it. Similar results were reported by Owolabi, Anig and Shuaibu [31]. Medical practitioners found biochemistry more interesting, relevant and less difficult than medical students. Furthermore, Gupta et al. [39] showed that, compared to medical students, residents perceive biochemistry as more “important to be a good physician”. On the other hand, graduates from a traditional medical curriculum occasionally complain about the amount of irrelevant knowledge and uninspiring content of biochemistry courses [30, see also 29].

However, the student perceptions did not correlate with the course examination performance. It should be taken into account that the usefulness ratings had relatively small variances, which might explain the lack of statistically significant correlations. It also indicates that the students’ perceptions were reasonably uniform. On the other hand, students’ are usually highly motivated to complete the courses and move on with the studies, regardless of their own interest in the topics. While student perceptions have been studied before, this study differentiated the student perceptions in terms of usefulness for future studies and usefulness for future profession. The purpose of this differentiation was to explore whether the medical students themselves recognise the role basic biomedical sciences play in their learning trajectory. Indeed, the basic science courses that received the lowest ratings for usefulness for future profession (UP) were still rated higher for usefulness for future studies (US). The findings highlight a possible communication gap; the relevance of cellular and molecular biology to medical profession (e.g. understanding of scientific literature, professional development) should be communicated more clearly to the students. Furthermore, basic science topics could benefit from a more integrative pedagogical approach in which the biomedical concepts are conceptualised in diagnostic practice [40].

The apparent mismatch between the emphases of medical curriculum and students' perceptions prompts also reflection on the more fundamental assumptions of medical education and what it means to be a medical professional. The fact that students perceive some of the curriculum somewhat irrelevant can be addressed in different ways. First, as mentioned above, the relevance of these topics can be communicated better to the students also via the implemented instructional approach. A more radical proposal would be to re-evaluate and revise the medical curriculum and examination procedures, especially when it comes to basic sciences. The notion that medical professionalism draws its legitimacy primarily from academic examination performance in basic biomedical sciences needs to be thoroughly examined and discussed by the medical community. While this discussion has been going on for decades and it has shaped medical curriculum to some degree [e.g. 13, 14], it has had quite limited effect on the matriculation and graduation requirements which are still focussed on academic performance.

In addition to the relatively small sample size, the study has limitations due to the restricted range of the entrance examination results and because no data about the internal reliability of the examinations was available. However, the study contributes to our knowledge about how and what kind of knowledge and perceptions do, or do not, improve students learning in biomedical sciences. Therefore, the results are applicable to medical educators and institutions beyond the context of this study.

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