Zeynep Gromley*, PhD, Chinelo Agwuncha, OMS, I, Vinayak K. Nahar, MD, PhD
and Adam Gromley, PhD

The effectiveness of the metabolic map in promoting meaningful learning

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Abstract

Context: Many medical students and practicing physicians view biochemistry, especially its metabolic pathways, as a challenging topic given the depth of material. Medical biochemistry educators aim to help prepare future physicians to apply knowledge of metabolism to disease processes. Research confirms that study tools promote critical thinking and help to connect biochemistry concepts to health and disease processes.

Objectives: To explore whether the Pathways of Human Metabolism Map as a study tool helps to connect basic metabolic pathways to clinical applications.

Methods: We provided the Pathways of Human Metabolism Map to our first-year osteopathic medical students and conducted a survey to assess their perceptions. Our survey questions aimed to explore the effectiveness of utilizing the metabolic map for connecting the basic metabolic pathways to clinical applications on their studies. Students were surveyed at the end of the course utilizing a Qualtrics survey encompassing Likert scale questions as well as open-ended responses.

Results: The results of our comprehensive survey questions revealed the unique perceptions of students. Analysis

of our data implicates that study tools like the metabolic map inspire meaningful learning.

Conclusions: Our data show that students who utilized the metabolic map in their studies reported that utilizing the map improved their understanding of medical biochemistry. Our research results suggest that providing study aids like the metabolic map encourages students to minimize rote memorization and promotes integration with clinical context. Our results provide a support for study strategies that implement meaningful learning in medical education.

Keywords: biochemistry; meaningful learning; medical education; metabolic map.

Understanding the biochemical basis of health and diseases is a crucial aspect of every medical school curriculum. Because nearly all diseases have an underlying biochemical etiology, the knowledge of biochemical pathways is essential to make a correct diagnosis and effectively treat patients. Nevertheless, many medical students and practicing physicians view basic science information including biochemistry and especially its metabolic pathways as a challenging topic given the depth of material [1].

Several factors have been reported by students as being obstacles in their learning of biochemical concepts [2]. The most common of these are the belief that the understanding of biochemistry comes from rote memorization and that the interactions among different metabolic pathways are not always apparent [1, 2]. To overcome these obstacles and to graduate competent physicians, educators in the health sciences are developing new teaching tools and methods [3]. To improve understanding of biochemical fundamentals, biochemistry educators have described methods, strategies, and approaches to the teaching of biochemistry, especially of metabolic pathways [4–10]. Overall, these studies concluded that rote memorization of the metabolic pathways are impractical and should be discouraged. Instead, the understanding and clinical applications of human metabolism should be the focus of teaching.

According to Oxford Learning ([oxfordlearning.com](https://www.oxfordlearning.com)), the concept of meaningful learning involves understanding

*Corresponding author: Zeynep Gromley, PhD, Department of Molecular Sciences, DeBusk College of Osteopathic Medicine, Lincoln Memorial University, Harrogate, TN, USA,
E-mail: zeynep.gromley@lmunet.edu. <https://orcid.org/0000-0002-8358-1941>

Chinelo Agwuncha, OMS, I, DeBusk College of Osteopathic Medicine, Lincoln Memorial University, Harrogate, TN, USA

Vinayak K. Nahar, MD, PhD, Department of Dermatology, School of Medicine, University of Mississippi Medical Center, Jackson, MS, USA; and Department of Preventive Medicine, School of Medicine/John D. Bower School, Jackson, MS, USA

Adam Gromley, PhD, Department of Pathology, DeBusk College of Osteopathic Medicine, Lincoln Memorial University, Harrogate, TN, USA

how all the pieces of an entire concept fit together. Toward meaningful learning, medical educators developed teaching methods and learning resources [11]. Despite the many teaching strategies available, metabolism remains a challenge for biochemistry educators. To implement meaningful learning, many biochemists utilize metabolic maps that have been created by educators, companies, and students to be utilized as study tools [12–15]. Several biochemistry educators have reported educational interventions for teaching metabolism and the advantages of using metabolic pathways maps [12, 13, 15].

Medical biochemistry educators often introduce these maps to assist students in bridging biochemical pathways to clinical applications. A metabolic map, Pathways of Human Metabolism Map, was developed by the Stanford University School of Medicine faculty for this purpose. Educators from Stanford University and the Association of Biochemistry Educators (ABE) standardized this resource as a learning and assessment tool (the map is available online here: <https://metabolicpathways.stanford.edu>).

The Pathways of Human Metabolism Map has been utilized in many medical schools for teaching, learning, and assessment. Although some schools provided it to their students solely as a study tool, other schools utilized it additionally as a resource during examinations. A study by Spicer et al. [15] reported benefits and disadvantages of using the Pathways of Human Metabolism Map in learning and assessment. In their study, they described the perspectives of students from three medical schools. They surveyed students with open-ended questions and asked students to describe or comment about the benefits and disadvantages of the metabolic map with regard to studying and/or taking examinations. The responses from a total of 481 students were examined and categorized into five main perceived benefits of the metabolic map to: (1) provide visual aid and mental organization of metabolic pathways; (2) promote deep learning, critical thinking, and understanding of clinical context; (3) reduce the needed time for memorization; (4) decrease anxiety for examinations; and (5) support long-term recall. Although these studies provide a cursory view regarding students' perceptions of the use of the metabolic map, insight into the degree of utilization of the map among the students was not assessed.

Here we describe a study that is the first to address the level of utilization of the metabolic map among osteopathic medical students and the first to evaluate these students' perceived confidence in their ability to link metabolic pathways to mechanisms of health and diseases. Our study gives important insights into the proportion of students that utilized the metabolic map in their studies and its impact on meaningful learning. Our results represent a comprehensive

measure for understanding the effectiveness of utilizing the metabolic map in the medical school curriculum.

Methods

We adapted the Pathways of Human Metabolism Map as a study aid and incorporated its use into the Molecular Fundamentals of Medicine (MFM) course given to first-year medical students. We sought to determine the utilization of the map and perceptions of first-year osteopathic medical students (OMS I) regarding the effectiveness of the metabolic map in the learning of medical biochemistry and the understanding of disease pathogenesis.

The Pathways of Human Metabolism Map was printed (18" × 36") and distributed to all OMS I right before the metabolism lectures started during the Fall of 2017 and the Fall of 2018 MFM course (Supplementary Figure). The MFM course covers cell and molecular biology, biochemistry, metabolism, and genetics, and it is offered in the first semester of OMS I year. In addition to distributing the print version, we also emailed and posted the PDF file of the metabolic map on our learning management system's course site. We encouraged students to use the metabolic map as a study tool by incorporating portions of the map into our Microsoft PowerPoint presentations whenever it was applicable. To assess the perceptions of students and utilization of the map, a link to the survey encompassing Likert scale questions as well as open-ended responses was sent via email to all students at the end of the course. Students were surveyed using a Qualtrics survey in compliance with Institutional Review Board (IRB) requirements. Participation in this study was completely voluntary, and participants were able to withdraw anytime from the study. A Qualtrics survey link was sent via email to all students who enrolled in the MFM course. An explanation of the study was provided in the email. Data were collected during a four-week period, and students received a reminder email after the first and second weeks. Our IRB reviewed our project entitled "Effectiveness of Metabolic Map in Medical Biochemistry Education" and determined that our proposed study is exempt from further IRB review (Protocol #641 V.1). The survey questions are shown in Figure 1. Likert scale results were analyzed in Microsoft Excel. Open-ended survey responses were reviewed and analyzed individually by the authors and grouped by common themes. The number of responses fitting each theme was then determined.

Results

Metabolic map utilization among OMS I students

At the end of the Fall 2017 and 2018 semesters, the Qualtrics survey was sent to OMS I students ($n=489$) in the MFM course. A combined total of 191 (39%) students responded to the survey (97 students in the Fall of 2017 and 94 students in the Fall of 2018). Of those that responded, 100 students (52.4%) (53 students [54.6%] in the Fall of 2017 and 47 [50.0%] students in the Fall of 2018) reported that they utilized the metabolic map during their studies, while 91

Figure 1: Survey questions. The respondents who utilized the map were prompted to answer a series of Likert-scale and open-ended questions.

Figure 2: Utilization of the map. At the end of the Fall 2017 and the Fall 2018 semesters, approximately 39% of the students responded to our survey.

respondents (47.6%) reported that they did not (Figure 2). Of those 100 students who did use the metabolic map, 31 students (31.0%) reported that they used the map “often” and seven students (7.0%) reported using it “always.” The remaining 62 students (62.0%) reported using the map “sometimes” for their studies. Of note, one student did not proceed past the first Likert scale question, thus there was a total of 99 respondents for the remaining survey questions.

The students that indicated that they used the metabolic map in their studies were prompted to answer a series of questions aimed at determining the effectiveness of the map for understanding and interpretation of clinical cases (Figure 1).

The impact of the metabolic map on student learning and the understanding of biochemistry and mechanism of diseases

The first two Likert scale questions aimed to examine students’ perspectives on the effectiveness of the map for understanding of biochemistry and mechanism of diseases (Figure 1). Seventy-eight students (78.9%) who responded to our survey either strongly agreed ($n=24$ or 24.2%) or agreed ($n=54$ or 54.5%) that the map had a positive impact on learning and understanding of biochemistry. Importantly, 93 respondents (93.9%) who used the metabolic map in their studies confirmed that the understanding of metabolic pathways is necessary to understand the mechanism of diseases. While four students (4.0%) reported as being neutral on this statement, only one student (1.0%) disagreed, and another student (1.0%) strongly disagreed. In addition to Likert scale, the students were given the opportunity to provide open-ended responses regarding their views on the importance of understanding metabolic pathways as a necessity for understanding the mechanism of diseases. A total of 33 students commented to this open-ended question. The 33 given responses shared common themes: “the map provided a big picture and showed how the pathways are connected,” “understanding the normal

Figure 3: The impact of the map in the interpretation of clinical biochemistry cases.

state is essential to understand disease processes,” and “understanding the pathways makes the understanding of diseases much easier.” One student commented that “it is very helpful to put disease into an overall picture rather than just symptoms, which is our underlying goal as an osteopathic physician!”

The effectiveness of the map in the interpretation of clinical biochemistry cases

The last Likert scale question aimed to examine the effectiveness of the metabolic map in the interpretation of clinical cases (Figure 1). Forty-three respondents (43.4%) agreed with the statement “The map helped me in the interpretation of the clinical biochemistry cases,” while 25 students (25.3%) strongly agreed with this statement (Figure 3). Only seven students (7.0%) disagreed with this statement, with an additional two students (2.0%) strongly disagreeing. The remaining 22 students (22.2%) were neutral.

In addition to the Likert scale, 26 students provided open-ended responses regarding their views on the effectiveness of the map in the interpretation of clinical cases. A majority of responses (19 out of 26, or 73.1%) stated that the map was useful in this regard, with the remaining seven (26.9%) indicating that the map was not helpful for interpreting clinical

cases. Students also reported that the map was useful with application questions utilized during Team-Based Learning (TBL) sessions. Unexpectedly, some commented that they learn the case first and then apply it to the map.

Benefits and disadvantages of the metabolic map

Students who utilized the metabolic map in their studies were also prompted to answer two open-ended back-to-back questions about the benefits and disadvantages of using the metabolic map (Figure 1). A total of 68 students responded to the question regarding the benefits of utilizing the map. Nearly all felt that the map provided an overview for connecting and integrating the pathways, helped visualize the big picture, and provided a quick and comprehensive reference during their studies. One student reported that the map would be helpful during exams.

Following this trend, the result from the Likert-scale question that asked “Would you like this map to be available to you during the exams?” showed that 78 out of the 99 respondents (78.9%) would like the map to be available during exams. Unexpectedly, 21 students (21.2%) indicated that they do not want the map to be available to them during the exams. Regrettably, we did not have any questions in the survey to probe further into their reasonings for this response.

For the open-ended question that asked about the disadvantages of utilizing the metabolic map for studying (Figure 1), a total of 64 students responded. Of the 64 responses, 29 students (45.3%) reported that they felt there were no disadvantages of using the metabolic map. Of the remaining 35 responses, most stated that the map was overwhelming, they were distracted by nonrelevant pathways, and the information density was daunting at first. As disadvantages for studying, some students commented on the physical properties of the map, such as being too big to carry around and having text that is too small to read.

Reasons for not utilizing the map

Out of the 191 survey respondents, 91 students (50 students [51.5%] in the Fall of 2017 and 41 students [43.6%] in the Fall of 2018) reported that they did not use the map during their studies (Figure 2). These respondents were prompted to answer an open-ended question of “Why didn’t you use the map?” (Figure 1). There was a total of 33 comments in the Fall of 2017 and a total of 24 comments in the Fall of 2018. The responses were grouped by common themes

Figure 4: Reasons for not utilizing the map.

(Figure 4). We counted a total of 35 comments that described the map as “overwhelming.” In addition, 27 of the comments described using other resources for their studies such as their lecture PowerPoints, their own class notes, or maps that they created on their own (Figure 4). While a small number of comments ($n=11$) claimed that the map lacks relevance to the class, 38.6% of the comments included references to the aforementioned inconvenient physical traits of the map, such as its size or organization, for the lack of utilization (Figure 4).

Discussion

Our study shows that 52.4% of respondents utilized the metabolic map as a study tool. Among those students, 33 students who utilized the map in their studies commented that the map provided the “big picture” and that it was a solid visual aid for connecting and cross referencing of multiple metabolic pathways. Responding students also found that the map was beneficial for their understanding of medical biochemistry, with most of the students (68 respondents, or 68.7%) indicating that their ability to interpret clinical cases was enhanced. Our results strengthen the idea that the metabolic map as a study aid can promote the application of basic knowledge into disease processes.

Although 78.9% of students who reported to utilize the map agreed or strongly agreed that it had a positive impact on their studies, there was one subset that raised our attention: the 21.2% of respondents who used the map in their studies but reported that they would not want the map available to

them during the exams. One of the omissions of our study is a lack of data on why students do not prefer to have the metabolic map during examinations. In designing this study, we assumed that students who used the map would naturally prefer having the map available to them during the examinations, thus not including an open-ended question to our survey was surely an oversight. We can only speculate that students may have concerns about complacency during their studies if they know that the map will be available to them during the exams. In support of this idea, students’ responses in similar studies suggest that the map may result in reduction in motivation for studying and may lead to under-preparation for course and licensing examinations [15].

Although our study did not address any correlations between individual students’ perspectives and their academic performances, we did not see a significant impact on overall class averages or exam item performances compared to students in previous years that did not have access to the map. Still, it would be important in future studies to address the potential impacts the map may have on the exam performance of those students that used it for their studies.

Another limitation is that our results represent only one osteopathic medical school student body. However, similar studies that used cohorts from multiple medical schools have shown that responses from individual schools do not differ drastically [15]. To address this, we plan future studies that will expand our subject pool to include students from other osteopathic schools. Nevertheless, our data provide important insights into the students’ perceptions regarding the use of the metabolic map. Our comprehensive survey data reveal the importance of developing study strategies

and study tools like the metabolic map. In particular, the perspectives of students presented in Figure 3 suggest that the metabolic map as a study tool promoted meaningful learning. We believe that providing these new or long-lasting study strategies to facilitate meaningful learning in biochemistry may help educators in other fields of medical education to develop similar study aids.

Interestingly, we also have anecdotal evidence that after two years of the implementation of the metabolic map into our curriculum, the faculty were motivated to write clinically relevant vignette-style exam questions. Critical-thinking test items are written at the application level and ask for high-level discrimination. It has become clear to us that an exam item asking, “Which enzyme requires thiamine for its activity?” drives students for rote memorization and does not promote clinical reasoning in medical students. However, writing a clinical vignette question describing a Wernicke-Korsakoff patient with signs and symptoms helps students connect metabolic pathways to clinical practice. In addition to adopting new teaching strategies and study tools, we think that medical science educators should also adopt improved assessment practices [16]. In support of this, our results indicate that clinical vignette questions help students connect the relevance of metabolic pathways to clinical medicine. Therefore, we believe that writing clinical vignette exam questions by applying the basic science topics to clinical scenarios will lead students to be fully engaged with science topics.

Our survey results reveal students’ perspectives regarding the use of the metabolic map as a study aid. Although our results provide insightful data for the effectiveness of the metabolic map in the medical biochemistry education, comparative studies are needed to analyze the correlation between students’ perspectives and their academic performance.

Conclusions

Our study suggests that study tools, like the metabolic map, are useful for students to learn the fundamentals of basic science. Additionally, our data suggest that the metabolic map helped students to link basic science to clinical applications and promoted meaningful learning of the metabolic pathways. Finally, our observations suggest that assessing the basic science information wherever it is applicable in a clinical context encourages students to learn basic science topics.

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Competing interests: None reported.

Ethical approval: Lincoln Memorial University’s Institutional Review Board (IRB) reviewed our project titled “Effectiveness of Metabolic Map in Medical Biochemistry Education” and determined that our proposed study is exempt from further IRB review (Protocol #641 V.1).

Informed consent: Participation in the study was completely voluntary and participants were able to withdraw anytime from the study. A Qualtrics survey link was sent via email to all students who enrolled in the MFM course. An explanation of the study was provided in the email. Data was collected during a four-week period of time, and students received a reminder email after the first week and second week.

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