10-26-2018

Medical Biochemistry Without Rote Memorization: Multi-Institution Implementation And Student Perceptions Of A Nationally Standardized Metabolic Map For Learning And Assessment

Douglas B. Spicer

Kathryn H. Thompson

Michelle S. Tong

Tina M. Cowan

Tracy B. Fulton

See next page for additional authors

Authors

Douglas B. Spicer, Kathryn H. Thompson, Michelle S. Tong, Tina M. Cowan, Tracy B. Fulton, and Janet E. Lindsley

Medical biochemistry without rote memorization: multi-institution implementation and student perceptions of a nationally standardized metabolic map for learning and assessment

Douglas B. Spicer, PhD, MMEdL; Kathryn H. Thompson, PhD, RDN; Michelle S. Tong, BA; Tina M. Cowan, PhD; Tracy B. Fulton, PhD; and Janet E. Lindsley, PhD.

D.B. Spicer, Department of Biomedical Sciences, University of New England College of Osteopathic Medicine, Biddeford, Maine. ORCID: https://orcid.org/0000-0002-7223-3423

K.H. Thompson, Department of Biomedical Sciences, University of New England College of Osteopathic Medicine, Biddeford, Maine. ORCID: https://orcid.org/ 0000-0002-0145-312X

M.S. Tong, Center for Faculty Educators, University of California, San Francisco School of Medicine, San Francisco, California.

T.M. Cowan, Department of Pathology, Stanford University School of Medicine, Palo Alto, California.

T.B. Fulton, Department of Biochemistry and Biophysics, University of California, San Francisco School of Medicine, San Francisco, California.

J.E. Lindsley, Department of Biochemistry, University of Utah School of Medicine, Salt Lake City, Utah. ORCID: https://orcid.org/0000-0002-5318-8268

Correspondence should be addressed to Douglas B. Spicer, telephone: 207-602-2186; e-mail: dspicer@une.edu.

Abstract

Despite the growing number of patients worldwide with metabolism-related chronic diseases, medical biochemistry education is commonly perceived as focusing on recall of facts irrelevant for patient care. The authors suggest that this focus on rote memorization of pathways creates excessive cognitive load that may interfere with learners' development of an integrated understanding of metabolic regulation and dysregulation. This cognitive load can be minimized by providing appropriate references during learning and assessment. Biochemistry educators collaborated to develop a medically relevant Pathways of Human Metabolism map (MetMap) that is now being used at many medical schools as a nationally standardized resource during learning and assessments. To assess impact, students from three medical schools were surveyed about its benefits and disadvantages. Responses were obtained from 481 students (84%) and were examined using thematic analysis. Five main themes emerged as perceived benefits of using the MetMap: 1) aids visual and mental organization, 2) promotes deep learning and applied understanding, 3) decreases emphasis on memorization, 4) reduces anxiety on exams, and 5) aids recall. Perceived disadvantages were: 1) fear of under-preparation for licensing exams, 2) overwhelming nature of the map, and 3) reduced motivation for and time spent studying. Results affirm that students perceive use of the MetMap promotes focus on broader metabolic concepts and deep versus surface learning, supporting a shift in cognitive load toward desired goals. Although the long-term impact on learning needs to be further studied, the use of the MetMap represents a step toward open-reference exams that reflect "real world" practice.

Background

Metabolism-related chronic diseases (*e.g.* obesity, diabetes, heart disease, stroke, many cancers) are increasingly causing patient suffering and straining healthcare systems worldwide. Applying understanding and solving problems related to metabolic regulation and dysregulation are therefore important skills for future physicians [1]. However, medical school biochemistry is often perceived as emphasizing recall of facts irrelevant for patient care [2]. One study found that most students entering health sciences fields expected to take a 'surface' approach to learning biochemistry through memorization, and few students viewed the topics as parts of a greater whole [3]. This is underscored by the growth of an industry that promotes memorization of disparate facts using mnemonics and nonsensical cartoons, which may contribute to biochemistry being the least retained basic science content between USMLE Steps 1 and 2 [4]. The authors receive frequent reminders from practicing physicians that forced memorization of the Krebs cycle during medical school was not only useless but traumatizing [1]. These observations and the ready availability of vast amounts of information at the tap of a finger raise the question: how can we ensure medical education is focused on the cognitive skills most germane to patient care, *i.e.* appropriately using references and problem-solving, rather than rote memorization?

Cognitive load theory holds that meaningful learning can be promoted by matching task complexity (*intrinsic load*) to learners' prior experience, by minimizing cognitive effort expended on nonessential aspects of a task (*extraneous load*), and by maximizing the processing and constructing of schemas needed for long term memory (*germane load*) [5]. One way to decrease overall cognitive load while maximizing germane learning is to provide reference

materials or graphic organizers that contain material that does not need to be memorized, as has been done with the periodic table of elements in chemistry [6]. We propose that provision of a map of metabolic pathways during learning will decrease the emphasis on memorizing the names of enzymes and intermediates and allow students to focus on the more germane task of understanding their roles in disease and diagnosis. Stanford University School of Medicine faculty created a map containing medically relevant metabolic pathways and collaborated with the Association of Biochemistry Educators (ABE), a national organization of health professions school biochemistry educators, to develop it into a standardized resource that is freely available for download (Pathways of Human Metabolism: https://metabolicpathways.stanford.edu/). A portion of the map is shown in Figure 1. Many schools use the map in teaching while also providing it as a reference for assessments, making a novel shift away from the historic emphasis on memorization in biochemistry.

Methods

To explore impact, we examined the use of the Pathways of Human Metabolism map (MetMap) in the teaching and assessment of biochemistry at three different medical schools: the University of California, San Francisco School of Medicine (UCSF); the University of Utah School of Medicine (Utah); and the University of New England College of Osteopathic Medicine (UNE). All three schools integrate biochemistry content with other topics in interdisciplinary courses longitudinally in the MS1 year, and the Utah curriculum revisits metabolism in the fall of the MS2 year. A searchable, digital version of the MetMap has been provided to students at all three schools for at least the last three years. Students are oriented to using the map when metabolism is first introduced, and instructors alternate between the use of small sections and the full map.

The MetMap is also provided as a resource that students can access to consult during assessments. Utah and UNE assessments consist primarily of multiple choice questions; UCSF assessments consist of open-ended questions.

At the end of the MS1 fall (Utah, December 2017), the end of the MS1 year (UNE, May 2017), and the end of the MS2 fall (UCSF and Utah, December 2017), we surveyed students on their perceptions about the benefits and disadvantage of using the MetMap during learning and assessment. Questions were open-ended with no character limitation. Survey questions are shown in Table 1. The two cohorts of Utah students and UNE students completed the survey immediately following courses that utilized the MetMap. UCSF students completed it six months following courses using the MetMap. Each institution's respective Institutional Review Board (IRB) independently approved the administration of the surveys and use of the survey data.

Following data collection, the researchers initially reviewed student survey responses and then conducted thematic content analysis. All authors individually performed initial and focused coding processes. Individuals cross-checked their coding structures and conducted detailed discussions to achieve consensus where mismatches occurred. Although the surveys were slightly different at the different schools, the themes that emerged across schools were very similar, as were the themes from responses to questions that targeted the effect of the map on studying versus assessment. The group reached a consensus for the final codebook and applied it to the data from student surveys using Dedoose software (SocioCultural Research Consultants, LLC version 7.5.9).

Results

The response rates of the surveys were 136/173 (78%)(UNE MS1), 129/150 (86%)(UCSF MS2), 89/125 (71%)(Utah MS1), and 127/128 (99%)(Utah MS2) for an overall response rate of 481/576 (84%). Emergent themes clustered into five main perceived benefits and three main disadvantages.

Benefits

Overall, students reported that the map was a useful tool for learning and assessment.

1) Aids visual and mental organization

Students reported that the map provided visual support in showing the connections between different metabolic processes and key shared enzymes. Students described how the color coding of the map helped them see relationships between the parts and the whole, in the context of normal function and disease. This visualization aided their mental organization and understanding, and students described being able to visualize the map and not needing to reference it during exams.

"[The map] helps connect pathways and provide a solid visualization and starting point to begin working. One of the things I noticed during exams is that, from using the metabolic map studying, I was able to think through most questions without looking at the map." (Utah, MS1)

"As a visual learner, the metabolic map helps me to put the pieces of the puzzle together and build visual/tangible connections between topics of study, which has been incredibly helpful to

my learning and understanding of various topics. I can't speak highly enough of this learning tool. I use it to test myself, to understand topics, and to integrate my knowledge." (UNE MS1)

2) Promotes deep learning and applied understanding

Students reported that the map allowed them to focus on learning broader concepts, critical thinking, and clinical applications of the material. Students described the map as being a useful tool in understanding the larger clinical relevance of metabolic dysfunction.

"I feel that the map is an absolute asset to our learning, as we are FINALLY being tested on our understanding and ability to apply knowledge, as we will have to do in the real world, rather than memorizing some random reactions that we would be able to google in five seconds if we were to need it in our practice of medicine…! I feel that I have been able to learn an incredible amount of useful clinical information (ie: genetic mutations, aberrant enzymatic function, etc) from using the map that I otherwise would not have had the brain space for if I would have had to memorize the reactions. With the map, I can use the reactions I am given to determine what enzyme may be faulty or diminished in a patient's case and what disease this might be - which is an awesome feeling of accomplishment (and extremely motivational, I might add) as just a first year medical student!" (UNE MS1)

"I really appreciate the emphasis on conceptual understanding rather than memorization. Using the map during exams allowed us to demonstrate that conceptual knowledge." (UCSF MS2)

3) Decreases emphasis on memorization

Students reported that having the map allowed them to reduce the amount of time spent on rote memorization of enzymes and pathways. Many of these comments were double-coded with one of the first two themes, with comments saying that the reduced need for memorization allowed them to focus on larger biochemical concepts and their clinical relevance, consistent with our hypothesis that a decrease in the extraneous load of memorizing helps maximize the germane learning.

"Not having to spend time memorizing the specific names in the metabolic map was the biggest benefit for me. I'm not very good at rote memorization and it often is frustrating to sit down and memorize a list of terms. I found it much more intuitive and enjoyable to focus on the map processes and rather than memorizing names, make sense of what these items relate to, which pathways they connect to, and make the map into literally a map, rather than a list of terminologies." (UCSF MS2)

"I think that having the metabolic map available is extremely beneficial. This allows students to spend more time learning why portions of the map are relevant, and their clinical context, rather than memorizing lists of enzymes/pathways. I would much rather be able to identify diseases than know the name of each metabolic enzyme." (Utah MS1)

4) Reduces anxiety for exams

In addition to allowing for an increased focus on relevant interactions and characteristics of pathways, students cited that having the map reduced stress and worry over comprehensively memorizing enzyme names and pathways for exams. Students commented that it was reassuring

to have the same resource to study with that was provided on the exam. Even students who reported not using the map during exams appreciated the reassurance its presence provided.

"I loved the metabolic map because it puts everything into perspective. I also tend to get stressed out in exams and just opening the map and double checking that I was sure about an enzyme's function by double-checking its location on the map would make exams less stressful in general." (Utah MS1)

"Absolutely essential to reduce unnecessary stress in graduate education. Memorizing small details for the sake of exams is incredibly unimportant in the long scheme and having these resources available during exams is such a powerful tool." (UCSF MS2)

5) **Aids recall**

Students described how repetitive use of the map while studying facilitated recall and reinforced material or reminded them of content they had forgotten. Students reported using the map on exams to assist with reasoning through pathways while not having to worry about errors in memorization of specific enzymes and substrates.

"On the exam it helps to jog my memory of the biochemistry needed to answer question. It can also help lead me to the right answers and feels like a safety net when I haven't memorized every single part of a pathway." (UNE MS1)

Disadvantages

Many students reported no disadvantages associated with using the map for studying or taking exams. However, other responses suggested concerns about the potential impact on preparation for course and licensing exams and motivation for studying biochemistry, as well as the overwhelming nature of the map.

1) **Leads to fear of underpreparation for licensing exams.**

Students expressed fears about being unable to use the MetMap during licensing exams. Students described it as a "crutch" that when available during course exams could leave them underprepared for Step 1. Some students refused to use the map for studying or on exams, while others appreciated its use in the course but felt they would need to memorize the pathways later for the licensing exams.

"If it is not included on the boards then it doesn't necessarily provide a tremendous service, as we will need to have it memorized, but frankly I am really getting to know the map well just by utilizing it so often on exams and in studying." (UNE MS1)

"The metabolic map is an excellent resource for learning and is a great framework for the information that I have committed to memory. I do feel that it can be somewhat of a crutch in preparing for Step 1 though, since we will not be able to use it on Step 1." (Utah MS2)

2) **Overwhelming nature of the map**

Some students were challenged by the comprehensiveness of the map and the amount of time it takes to navigate, although some mentioned that it became less overwhelming with continued use. Some students cited difficulties navigating the electronic version of the map with exam software that had no search function.

"I think it was less advantageous to use early on simply because I wasn't familiar with it and it took a while just to locate what I was looking for on it, but over time with repetitive use this problem went away as I got more and more familiar with it and it became less daunting to look at." (UNE MS1)

"Due to the map's complicated nature, sometimes on exams I would get overwhelmed trying to remember the complicated pathways and couldn't remember very simple relationships or pathways. A simpler version may be fitting." (UCSF MS2)

3) Reduces motivation for and time spent studying

Parallel to students reporting satisfaction with the reduced time spent memorizing afforded by the map, some described concerns about spending less time studying metabolism, that they retained less, or that they did not learn as much.

"I feel that because I had the metabolic map, I didn't study as much and in terms of long term memory, I feel that I retained less because of that. However, I feel that with review, I will be able to re-learn what I need to for Step." (UCSF MS2)

Discussion

Our findings suggest that the MetMap is a learning tool that helps most students go beyond a surface approach to learning biochemistry and focus on broader metabolic concepts, deep learning, and clinical application of biochemistry. These student comments suggest that the use of the MetMap helps reduce the cognitive load associated with rote memorization, while promoting germane learning of the clinical relevance of the regulation and dysregulation of metabolic pathways.

For some students the map seemed to add to the complexity of learning metabolism. This agrees with studies demonstrating that performance on items with diagrams depends on previously constructed knowledge schemata and familiarity with the diagram [7]. The MetMap is complex and like other graphic organizers, learning to use it does carry a cognitive load [8]. Initial introduction to a simplified, *advance organizer* companion to the map is a useful scaffolding mechanism [9], along with introducing small sections of the map prior to referencing those sections on the whole map. Some students may need more time on these tasks in order to effectively use the whole map. However, students who consistently used the MetMap for studying commented that they often did not need to refer to the map during assessment, supporting the notion that the MetMap provides critical scaffolding for learning.

Limitations of the current study include the use of different survey questions at the three medical schools, and surveying the students at different time intervals following completion of relevant courses. Yet the striking similarities in themes that emerged at each of the schools, which have

different curricular structures and approaches to teaching and assessment, suggest generalizability of the impact of the MetMap on learning.

The use of the MetMap represents a step toward open-reference exams, an assessment approach more representative of "real world" practice [10]. A systematic review comparing open-book and closed-book examinations found performance on the latter to be better, but acknowledged that performance could improve as faculty and students gain experience with open-book exams, and concluded that a combined approach provides the opportunity to improve assessment authenticity [11]. While we have not formally studied impact on student learning outcomes, none of the authors have detected a decrease in average student examination performance since introduction of the MetMap (data not shown). A detailed analysis of student performance and attitudes since the introduction of the map would be useful.

Whether or not metabolic pathway details need to be memorized for high-stakes licensing exams, students perceive this to be the case. The United States Medical Licensing Exam (USMLE) Management Committee approved exploration of the logistics and potential impact of including the MetMap on future Step exams, but analysis is ongoing and as of the June 2018 USMLE Metabolic Map Task Force meeting attended by several of the authors no date for implementation has been set. Until students are given reference materials on high-stakes exams, they will continue to perceive rote memorization as a critical task, which may come at the expense of developing a deep understanding of basic science essential for the optimal care of their patients.

Acknowledgments: The authors thank Steven Haist, MD, and Christy Bracken-Vasquez, MBA, at the National Board of Medical Examiners for hosting multiple meetings and discussions about the MetMap and licensing exams; Holly Nishimura, MPH, for help reviewing the literature; and Arianne Teherani, PhD, Bridget O'Brien, PhD, and Judith Bowen, MD, FACP, for feedback about the conceptual framework and data analysis; and Justin Sewell, MD, MPH, and Patricia O'Sullivan, EdD, for critical review of the manuscript.

Funding Information: Research assistant supported by the UCSF Academy of Medical Educators Chair for Excellence in Foundational Teaching.

Conflicts of Interest: JEL, TMC, and TBF serve on the USMLE Metabolic Map Task Force; JEL and TBF have served on USMLE Item-Writing Committees and on USMLE Step 1 Interdisciplinary Review Committees.

Compliance with Ethical Standards: This study was determined to be exempt from full review by the institutional review boards of all three institutions.

References

1. Fulton TB, Ronner P, Lindsley JE. Medical Biochemistry in the Era of Competencies: Is it Time for the Krebs Cycle to go? *Medical Science Educator.* 2012;22(1):29-32.
2. Schumann JH. Would Doctors Be Better If They Didn't Have To Memorize? *Shots: Health news from NPR* 2015; https://www.npr.org/sections/health-shots/2015/04/21/401254790/would-doctors-be-better-if-they-didnt-have-to-memorize. Accessed June 19, 2018.
3. Minasian-Batmanian LC, Lingard J, Prosser M. Differences in students' perceptions of learning compulsory foundation biochemistry in the health sciences professions. *Adv Health Sci Educ Theory Pract.* 2005;10(4):279-290.
4. Ling Y, Swanson DB, Holtzman Km, Bucak SD. Retention of basic science information by senior medical students. *Academic Medicine.* 2008;83(10):S82-85.
5. Young JQ, Van Merrienboer J, Durning S, Ten Cate O. Cognitive Load Theory: implications for medical education: AMEE Guide No. 86. *Med Teach.* 2014;36(5):371-384.
6. Stull AT, Mayer RE. Learning by doing versus learning by viewing: Three experimental comparisons of learner-generated versus author-provided graphic organizers. *Journal of Education Psychology.* 2007;99(4):808-820.
7. Kragten M, Admiraal W, Rijlaarsdam G. Diagrammatic Literacy in Secondary Science Education. *Research in Science Education.* 2012;43(5):1785-1800.
8. Offerdahl EG, Arneson JB, Byrne N. Lighten the Load: Scaffolding Visual Literacy in Biochemistry and Molecular Biology. *CBE Life Sci Educ.* 2017;16(1).
9. Bayardo TB. An advance organizer for the teaching of metabolism. *Biochemical Education.* 1993;21(4).
10. Moynahan KF. The Current Use of United States Medical Licensing Examination Step 1 Scores: Holistic Admissions and Student Well-Being Are in the Balance. *Acad Med.* 2018;93(7):963-965.

11. Durning SJ, Dong T, Ratcliffe T, et al. Comparing Open-Book and Closed-Book Examinations: A Systematic Review. *Acad Med.* 2016;91(4):583-599.

Figure Legends

Figure 1: This represents the MetMap in the background with the section outlined with a red box blown up on the right side. The full map is freely available at:

https://metabolicpathways.stanford.edu/

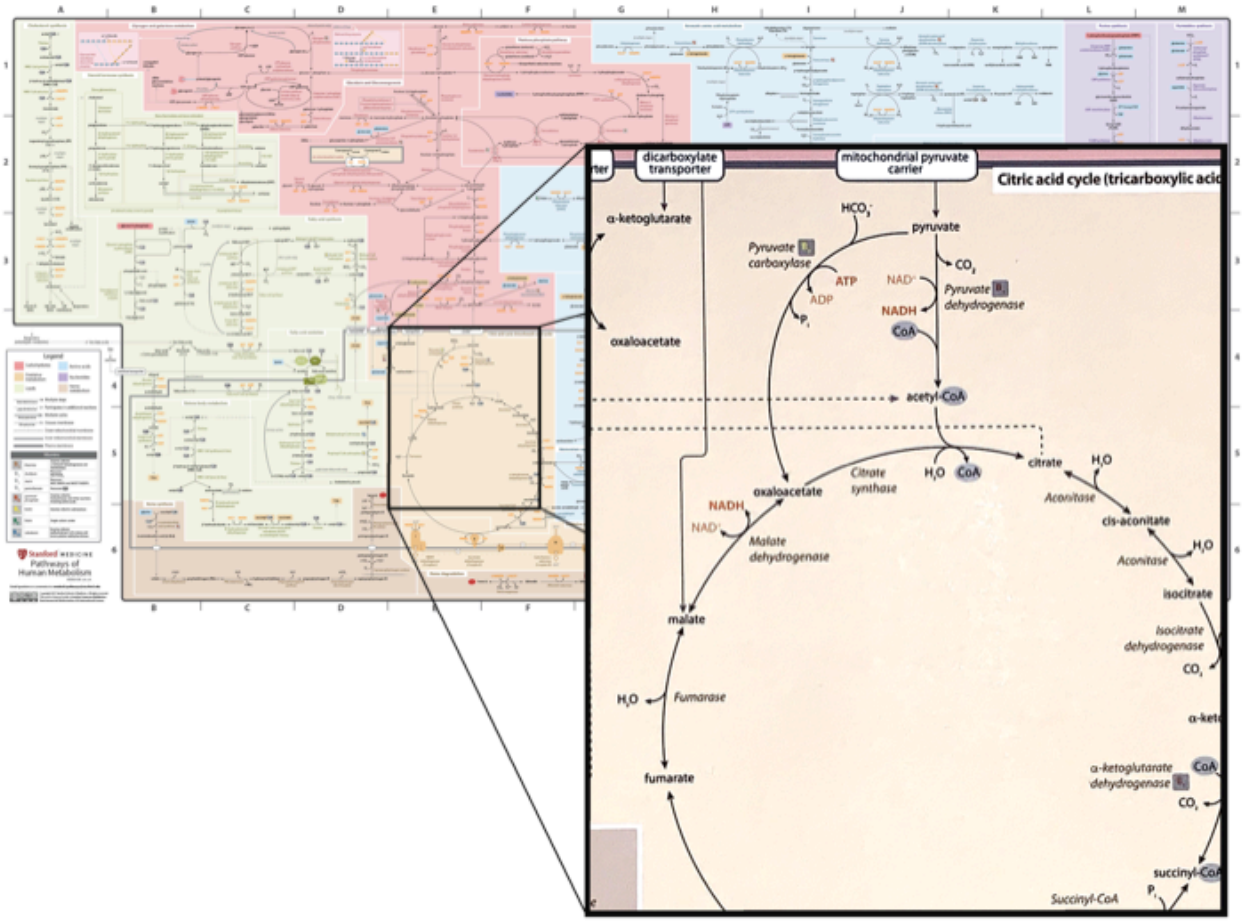

Table 1: The surveys that were used in this study

UCSF Survey
Briefly describe any benefits you feel the metabolic map provided with regard to studying.
Briefly describe any benefits you feel the metabolic map provided with regard to taking exams.
Briefly describe any disadvantages you feel the metabolic map created with regard to studying.
Briefly describe any disadvantages you feel the metabolic map created with regard to taking exams.
UNE Survey
Briefly describe any benefits you feel the metabolic map gives you for studying.
Briefly describe any benefits you feel the metabolic map gives you when taking an exam.
Briefly describe any disadvantages you feel the metabolic map creates when taking an exam.
Utah Survey
Do you have any comments about the benefits or disadvantages the metabolic map provided during either studying or exams?