A conceptual framework for the core concept of “cell membrane”

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Michael J, Modell H. A conceptual framework for the core concept of “cell membrane.” Adv Physiol Educ 43: 373–377, 2019; doi:10.1152/advan.00051.2019.—We have created and validated a conceptual framework for the core physiology concept of “cell membrane.” The conceptual framework is composed of 27 items arranged in a hierarchy that is, in some instances, four levels deep. We have validated it with input from faculty who teach at a wide variety of institutional types. All items making up the framework were deemed essential to moderately important. However, some of the main ideas were clearly judged to be more important than others. Furthermore, the lower in the hierarchy an item is located, the less important it is thought to be. Finally, there was no significant difference in the ratings given by faculty at different types of institutions.

INTRODUCTION

A core concept is

... well tested, validated, and absolutely central to the discipline. Each integrates many different findings and has exceptionally broad explanatory scope. Each is the source of coherence for many key concepts, principles, and even other theories in the discipline (1).

Michael and McFarland (5) published a list of 15 core concepts in physiology that was based on surveys of a diverse group of physiology teachers. Respondents to the initial survey were also asked to rank order the 15 core concepts they proposed in terms of their importance to their students.

Each core concept integrates the many smaller ideas and concepts that are its components. The process of systematically listing and organizing these component ideas is referred to as “unpacking” the core concept (2, 3, 6), and the result is called a conceptual framework.

We have previously published conceptual frameworks for the core concepts of flow down gradients (5), homeostasis (4), and cell-cell communication (7).

Here we present a conceptual framework for the core concept of “cell membrane.”

METHODS

We have described the core concept of cell membrane as follows (5, 6): “Plasma membranes are complex structures that determine what substances enter or leave the cell. They are essential for cell signaling, transport, and other processes.”

Unpacking this core concept (big idea) required us to systematically determine, in a structured way, the sub-ideas that make up this core concept (2, 3, 6). The general idea is to take each important term in an item and define and explain it. This can continue to whatever level is appropriate for the students for whom it will be used. Commonly used textbooks of physiology were consulted to establish what topics related to cell membranes are typically covered in physiology courses (at any post-secondary level) and ought to be in the conceptual framework.

Our conceptual frameworks have all been developed as tools to help teachers teach and students master the discipline of physiology; the conceptual frameworks have never been intended to be descriptions of everything that physiology now knows about the core concepts unpacked (6). Nor do we believe that our conceptual frameworks, as written, will work equally well for all students. Each teacher must decide what to add or what to subtract. In this regard, the words of Arthur Vander are of some relevance (9). In a paper entitled “Some difficult topics to teach (and not teach) in renal physiology,” he made the following observation: “... in keeping with one of my major teaching rules—you should never lie but you don’t need to tell the entire truth.” We have not attempted to tell the whole truth, but we have attempted to describe everything we think undergraduate students are likely to need.

The conceptual framework for the core concept of cell membrane contains 27 items (see Table 1).

Surveys containing the conceptual framework were prepared in both paper and electronic versions and distributed online and at professional meetings.

A 5-point Likert scale was used to rate each item in the conceptual framework, with 5 = essential, 4 = important, 3 = moderately important, 2 = slightly important, and 1 = NOT important “for your students to understand.” Respondents were asked to rate each of the 27 items on the 5–4–3–2–1 scale. Across all 35 surveys that we received, there was a total of 12 different individual items that were not rated; the reason(s) for these omissions is not known.

Respondents were also asked to offer comments on the conceptual framework we had created. Eighteen of the thirty-five respondents submitted written comments of varying length.

RESULTS

Over one-half of the respondents (18/35) teach at research universities (Table 2). This number may be inexact, since some individuals teach both in undergraduate programs and in a professional school.

The conceptual framework for cell membrane consists of a 27-item, 4-level hierarchy (Table 1). For each item in the conceptual framework, the numbers of ratings of each value were tabulated, and the average rating was calculated and is displayed in this table. The most appropriate way to treat Likert-scale data continues to generate some disagreement, but using the average values to rank order the importance of the items is generally regarded as acceptable (8).
The structure of the conceptual framework is more readily appreciated by an examination of its visual representation seen in Fig. 1. The relationship between the ideas making up the conceptual framework and the number of items at each level can be seen directly. The average rating for each item is also visible.

The ratings for the items making up the conceptual framework obtained from our 35 respondents show the following (see Table 1).

The average ratings of each of the 27 items making up the conceptual framework ranged from a high of 4.9 (slightly less important, 4 = important, 3 = moderately important, 2 = slightly important, and 1 = NOT important. Avg., average rating.

### Table 1. The cell membrane conceptual framework

| Item No. | Core Concepts | Avg. | 5 | 4 | 3 | 2 | 1 |
|---|---|---|---|---|---|---|---|
| 1 | CM1 | The cell membrane is a lipidprotein bilayer. | 4.6 | 26 | 3 | 5 | 0 | 0 |
| 2 | CM1.1 | The bilayer consists of two layers of phospholipid molecules, each with a polar head (hydrophilic) and two nonpolar (hydrophobic) tails. | 4.5 | 24 | 8 | 2 | 0 | 1 |
| 3 | CM1.2 | The cell membrane includes a number of different types of molecules, including proteins (the fluid mosaic model). | 4.7 | 27 | 5 | 3 | 0 | 0 |
| 4 | CM1.2.1 | Some proteins are embedded in and span the membrane. | 4.0 | 14 | 9 | 7 | 2 | 1 |
| 5 | CM1.2.2 | Some proteins are attached to either the interior or exterior of the membrane | 3.8 | 12 | 9 | 9 | 3 | 1 |
| 6 | CM2 | The cell membrane participates in a variety of mechanisms that maintain the integrity of cells and make possible the specialized function of any cell. | 4.9 | 32 | 3 | 0 | 0 | 0 |
| 7 | CM2.1 | The cell membrane creates a closed space that contains the biochemical “machinery” needed for the cell to live and reproduce. | 4.5 | 23 | 6 | 5 | 1 | 0 |
| 8 | CM2.2 | The cell membrane helps to determine solute concentrations inside the cell to preserve the viability of the cell and the continuation of its specialized functions. | 4.7 | 27 | 6 | 1 | 1 | 0 |
| 9 | CM2.2.1 | Lipid soluble molecules (O2, CO2, urea) can passively diffuse across the membrane through the lipid portion of the membrane. | 4.4 | 20 | 10 | 3 | 0 | 1 |
| 10 | CM2.2.2 | Water and water-soluble substances (ions, most organic molecules) can only cross the membrane via mechanisms that involve membrane proteins. | 4.6 | 24 | 8 | 3 | 0 | 0 |
| 11 | CM2.2.2.1 | Water and some ions traverse the membrane by passive diffusion down an energy (osmotic or electrochemical) gradient through fluid filled channels (membrane spanning proteins). | 4.6 | 25 | 7 | 3 | 0 | 0 |
| 12 | CM2.2.2.2 | Some substances (e.g., ions, glucose, amino acids) traverse the membrane passively down a gradient via carrier molecules (proteins) in the membrane. | 4.3 | 21 | 6 | 7 | 1 | 0 |
| 13 | CM2.2.2.3 | Some substances traverse the membrane against a concentration gradient using ATPase powered pumps (primary active transport). | 4.6 | 24 | 9 | 2 | 0 | 0 |
| 14 | CM2.2.2.4 | Some substances traverse the membrane against a concentration gradient using membrane transporters that move one species across the membrane against a concentration gradient, and one species along a concentration gradient generally created by an ATPase located at a different location on the cell membrane (secondary active transport). | 4.5 | 19 | 13 | 3 | 0 | 0 |
| 15 | CM2.2.2.5 | The membrane also participates in the processes of endocytosis and exocytosis, energy-requiring processes that move things across the membrane in vesicles. | 4.2 | 18 | 9 | 5 | 3 | 0 |
| 16 | CM2.2.2.6 | Some cell membranes have connections to adjacent cells (gap junctions) that allow movement of substances from one cell to another along an electrochemical gradient. | 4.0 | 14 | 10 | 9 | 2 | 0 |
| 17 | CM2.3 | The cell membrane participates in cell-to-cell communication. | 4.9 | 30 | 2 | 1 | 0 | 0 |
| 18 | CM2.3.1 | Some cell membranes contain voltage-gated ion channels (proteins). | 4.6 | 25 | 7 | 2 | 1 | 0 |
| 19 | CM2.3.2 | Some cell membranes contain ligand-gated ion channels (proteins). | 4.5 | 24 | 7 | 3 | 1 | 0 |
| 20 | CM2.3.3 | Some cell membranes contain receptors (proteins) that, when bound to a ligand, activate a second-messenger system within the cell. | 4.5 | 23 | 8 | 3 | 1 | 0 |
| 21 | CM2.3.4 | Some cell membranes contain enzymes (e.g., acetylcholinesterase) that remove a ligand from the cell receptor site. | 3.7 | 8 | 14 | 8 | 5 | 0 |
| 22 | CM2.4 | Some cell membranes help maintain the integrity of tissues (e.g., epithelium) by forming junctions between cells. | 4.2 | 15 | 11 | 3 | 3 | 0 |
| 23 | CM2.4.1 | Tight junctions form between certain cells (e.g., epithelial cells) near the apical side of the cell. | 3.9 | 11 | 11 | 8 | 4 | 0 |
| 24 | CM2.4.1.1 | Tight junctions limit the passage of various substances (molecules, ions, water) through the space between cells. | 3.9 | 10 | 14 | 6 | 4 | 0 |
| 25 | CM2.4.1.2 | They block the movement of membrane components within the fluid mosaic from the apical to the basolateral side of the cell. | 3.5 | 8 | 9 | 10 | 7 | 0 |
| 26 | CM2.4.2 | Adherens junctions and desmosomes provide strong mechanical attachments between adjacent cells. | 3.5 | 5 | 12 | 11 | 6 | 0 |
| 27 | CM2.5 | The membranes of some cells (e.g., lymphocytes) contain proteins that serve as cell recognition proteins and participate in the organism’s immune system. | 3.7 | 10 | 13 | 5 | 4 | 1 |

Ratings of importance of items by 35 respondents are as follows: 5 = essential, 4 = important, 3 = moderately important, 2 = slightly important, and 1 = NOT important. Avg., average rating.
than “essential”) to a low of 3.5 (slightly more than “moderately important”).

Every one of the 27 items had at least five or more ratings of 5 (“essential”), and only five items each received a single rating of 1 (“NOT important”).

Based on these results, we conclude that our respondents found the conceptual framework to be a valid unpacking of the core concept of cell membrane.

Our respondents teach at five kinds of educational institutions (see Table 2), and the responses from different types of institutions do not show any obvious difference. The average rating by respondents at community colleges and 4-yr colleges (4.28) was compared with the average rating from respondents teaching at research universities and professional schools (4.30) for all 27 items. This difference is similar to the results for the cell-cell communications conceptual framework (7).

Whereas in both instances the sample sizes were too small to do statistical testing for the significance of any differences, the conclusion that has been drawn is a very limited one.

There is some suggestion that the items at the top two levels of the hierarchy are viewed as more important than items at the two lower levels (Table 3). This too was found in evaluating the cell-cell communications conceptual framework (7).

Eighteen of the thirty-five respondents provided written comments about the conceptual framework. These varied in length from a few words to a page of text. The comments could be sorted into five categories (see Table 4 for samples of comments in each of the categories).

The largest group of comments offered suggestions for additions to the conceptual framework. There were a few comments that suggested that some aspects of the “science” were out of date or wrong, or that, in omitting something, we had gotten the “science” wrong. We comment on these criticisms in the next section.

DISCUSSION

An examination of the numerical ratings for the 27 items making up the “cell membrane” conceptual framework supports a conclusion that it is made up of a set of ideas that physiology faculty regard as important for students to understand. The ratings ranged from a high of 4.9 (slightly less than essential) to a low of 3.5 (slightly more than moderately important).

As with the other conceptual frameworks that we have validated (4, 5, 7), it appears that items higher in the hierarchy are rated somewhat higher than items lower in the hierarchy (see Table 3 and Fig. 1). This makes sense, since the structure we built is organized to support this feature.

Finally, it appears that there is little obvious difference in the ratings of the items from community college and 4-yr college faculty compared with the ratings from faculty at research universities and professional schools.

The list of core concepts and the conceptual frameworks that have been developed are not intended to define the contents of a physiology course or even a piece of a physiology course (6). They do not define the learning objectives for any particular course. Nor are they intended to define the contents of a physiology major or curriculum. They are meant to provide teachers and students with tools for thinking about the many and varied systems making up the body.

The fact that faculty who teach physiology regarded the set of ideas making up this cell membrane conceptual framework to be important for their students to understand does not mean that the conceptual framework will be equally useful for students in all courses. The comments made by respondents

| Types of Institutions                        | No. of Respondents |
|----------------------------------------------|--------------------|
| 2-yr Community colleges (2year)              | 3                  |
| 4-yr College granting only BS/BA degrees (4yearBA) | 4                  |
| 4-yr College granting BS/BA degrees and some graduate degrees (4year) | 7                  |
| Research university (ResU)                   | 18                 |
| Professional school: medical, dental, nursing (Prof) | 3                  |
| **Total no. of respondents rating the survey** | **35**             |

BA, Bachelor of Arts; BS, Bachelor of Science. *The counts of ResU and Prof faculty may be inexact, because some faculty teach in both the professional school and the undergraduate college.

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For example, there are comments that suggested a number of “omissions” in the conceptual framework: ideas that might have been present but were not there. The science underlying the core concept of cell membrane has certainly advanced greatly in recent years. However, not all of the latest additions to the model for cell membranes need to be learned by students in some courses (9).

Similarly, some respondents identified what they regarded as errors in some of the ideas we included in the conceptual framework. Typically these comments referred to advances in the science that were not reflected in the conceptual framework. We anticipate that the framework will be refined as these and additional complexities revealed by future research become essential for understanding mechanisms covered by the majority of courses. These decisions will, of course, be made by individual teachers, reflecting the needs of their students.

Errors in the survey (missing words) were corrected as they were pointed out to us. However, other than correcting typos present in the surveys, we have not made changes to Table 3.

### Table 3. Rating of items at different levels in the hierarchy of the conceptual framework

| Category | Average of All Ratings at the Indicated Level in the Hierarchy |
|----------|---------------------------------------------------------------|
| CM1 | 26 3 5 0 0 |
| CM1.1 | 32 3 0 0 0 |
| CM1.2 | 24 8 2 0 1 |
| CM1.3 | 27 5 3 0 0 |
| CM1.4 | 23 6 5 1 0 |
| CM2.1.1 | 27 6 1 1 0 |
| CM2.2.2 | 30 2 1 0 0 |
| CM2.3.1 | 15 11 3 3 0 |
| CM2.4.1 | 10 13 5 4 2 |
| CM2.5 | 4.77 |

| Category | Average of All Ratings at the Indicated Level in the Hierarchy |
|----------|---------------------------------------------------------------|
| CM1.1 | 14 9 8 2 1 |
| CM1.2 | 12 9 9 3 1 |
| CM1.3 | 20 10 3 0 1 |
| CM1.4 | 24 8 3 0 0 |
| CM2.1.1 | 25 7 2 1 0 |
| CM2.2.2 | 24 7 3 1 0 |
| CM2.3.1 | 23 8 3 1 0 |
| CM2.4.1 | 8 14 8 5 0 |
| CM2.5 | 11 11 8 4 0 |
| CM2.2.2.1 | 5 12 11 6 0 |
| CM2.2.2.2 | 25 7 3 0 0 |
| CM2.2.2.3 | 21 21 1 0 0 |
| CM2.2.2.4 | 9 2 0 0 0 |
| CM2.2.2.5 | 19 13 3 0 0 |
| CM2.2.2.6 | 18 9 5 3 0 |
| CM2.2.2.7 | 14 10 9 2 0 |
| CM2.2.2.8 | 10 14 6 4 0 |
| CM2.4.1.1 | 8 9 10 7 0 |
| CM2.4.1.2 | 4.46 |
| CM2.4.2.1 | 4.30 |
| CM2.4.2.2 | 4.22 |

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(see Table 4) certainly suggested changes that could be made to the conceptual framework.

For example, there are comments that suggested a number of “omissions” in the conceptual framework: ideas that might have been present but were not there. The science underlying the core concept of cell membrane has certainly advanced greatly in recent years. However, not all of the latest additions to the model for cell membranes need to be learned by students in some courses (9).

Similarly, some respondents identified what they regarded as errors in some of the ideas we included in the conceptual framework. Typically these comments referred to advances in the science that were not reflected in the conceptual framework. We anticipate that the framework will be refined as these and additional complexities revealed by future research become essential for understanding mechanisms covered by the majority of courses. These decisions will, of course, be made by individual teachers, reflecting the needs of their students.

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### Table 4. Categories of written comments from survey respondents and samples of each type

| Category No. | Category |
|--------------|----------|
| 1 | Comments about concepts or subideas that are missing in the conceptual framework |
| “The concept of transport saturation should also be addressed using, for example, the secondary co-transport Na/glucose, as well as the competition process.” |
| “I might consider adding one comment about mechanotransduction, since it seems to be very important in cell function and relevant to disease.” |
| 2 | Comments about purported errors in the “science” described in the conceptual framework |
| “This ignores recent work in the requirement of CO2 channels for efficient transport.” |
| “Even cholesterol and fatty acids are facilitated by transporters, so I think this idea is largely bunk.” |
| 3 | Comments about the organization of the conceptual framework |
| “Another way to organize would be to use the 4 major functions of membrane proteins: structural, enzymes, receptors, and transporters.” |
| 4 | Comments about “errors” in the survey (typographical errors, poor wording) |
| “2.2.2.5—This was slightly confusing: ‘move things across the membrane in vesicles.’ Perhaps change to → move substances out of the cell via vesicle fusion with the cell membrane and subsequent diffusion of vesicle contents into the ISF.” |
| “CM 2.4 had an incomplete sentence. I think that section is missing what I added on cytoskeleton and matrix.” |
| 5 | Miscellaneous (general confirmation of appropriateness of conceptual framework; comments about what and/or how the respondent teaches this subject) |
| “I like to bring in mass balance, vesicular transport, adds and subtracts from membrane area.” |
| “This is looking really great.” |
the conceptual framework. Instead, we would urge all faculty interested in using this (cell membrane) or any of our other conceptual frameworks to edit them in any manner that preserves their accuracy but better serves their students as learning tools; this could include rewording component ideas, adding ideas, or changing the organization. Our goal all along has been to create tools to help teachers and students as they grapple with the difficult topics of physiology.

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DISCLOSURES

No conflicts of interest, financial or otherwise, are declared by the authors.

AUTHOR CONTRIBUTIONS

J.M. and H.M. conceived and designed research; J.M. and H.M. performed experiments; J.M. and H.M. analyzed data; J.M. and H.M. interpreted results of experiments; J.M. prepared figures; J.M. and H.M. drafted manuscript; J.M. and H.M. edited and revised manuscript; J.M. and H.M. approved final version of manuscript.

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