HOW WE TEACH | Generalizable Education Research

Cognitive flexibility and undergraduate physiology students: increasing advanced knowledge acquisition within an ill-structured domain

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Submitted 25 July 2016; accepted in final form 30 May 2017

Rhodes AE, Rozell TG. Cognitive flexibility and undergraduate physiology students: increasing advanced knowledge acquisition within an ill-structured domain. Adv Physiol Educ 41: 375–382, 2017; doi:10.1152/advan.00119.2016.—Cognitive flexibility is defined as the ability to assimilate previously learned information and concepts to generate novel solutions to new problems. This skill is crucial for success within ill-structured domains such as biology, physiology, and medicine, where many concepts are simultaneously required for understanding a complex problem, yet the problem consists of patterns or combinations of concepts that are not consistently used or needed across all examples. To succeed within ill-structured domains, a student must possess a certain level of cognitive flexibility: rigid thought processes and prepackaged informational retrieval schemes relying on rote memorization will not suffice. In this study, we assessed the cognitive flexibility of undergraduate physiology students using a validated instrument entitled Student’s Approaches to Learning (SAL). The SAL evaluates how deeply and in what way information is processed, as well as the investment of time and mental energy that a student is willing to expend by measuring constructs such as elaboration and memorization. Our results indicate that students who rely primarily on memorization when learning new information have a smaller knowledge base about physiological concepts, which is displayed by higher scores on a prior knowledge assessment and unit exams. However, students who rely primarily on elaboration when learning new information have a more well-developed knowledge base about physiological concepts, which is displayed by higher scores on a prior knowledge assessment and increased performance on unit exams. Thus students with increased elaboration skills possibly possess a higher level of cognitive flexibility and are more likely to succeed within ill-structured domains.

Another concept to arrive at a correct conclusion, even though the conclusion itself might appear very different compared with the parts from which it was constructed.

The importance of recognizing the role cognitive flexibility plays in the success of undergraduate physiology students cannot be overstated. Physiology is an integrated discipline requiring students to tap into previously learned information from many other fields, such as physics, biochemistry, and even evolution to fully grasp and appreciate the complexity of physiological concepts. In addition, physiology requires students to understand that oftentimes more than one answer can be correct, and that multiple processes can be used to arrive at a correct conclusion. To accomplish this, students must be able to assess multiple pathways and relationships and predict how changes in one area will cause changes in other areas of the body. This amalgam of concepts and multiplicity of avenues that could potentially lead to correct answers can be very confusing to most students enrolled in physiology courses; this is especially true for those with low prior knowledge levels in physiology or in prerequisite subjects that are required to understand physiology. For students with low prior knowledge, the amount of frustration toward the learning process grows, while overall success in the course wanes, which can lead to an increased reliance on surface-level learning techniques, such as rote memorization, when preparing for exams, oversimplification of concepts presented during class, and a linear approach to comprehending complex concepts in an effort to just get by (6, 7). Unfortunately, these tendencies are at odds with the process of advanced knowledge acquisition and success in more advanced physiology courses.

Advanced knowledge acquisition refers to a time of learning that occurs after an introductory stage but before the achievement of practiced expertise, which results from experience (6, 7). It requires students to transition away from an introductory learning approach, where surface level learning and a general familiarity with a field are usually sufficient, to a deeper, more meaningful level of learning that is often required in upper level courses and in future careers. With introductory learning, the goal is often mere exposure to content and the provision of a general orientation to a field; objectives of assessment are likewise confined to the simple effects of exposure and usually consist of recognition and recall (6). But at some point students must transition to a deeper level of learning and apply the information they have learned to new and novel situations, if they are to begin the process of advanced knowledge acquisition.

THE CAPACITY TO ATTAIN, USE, and apply conceptual knowledge in an adaptive fashion, which results in the generation of novel solutions to problems that have never before been encountered, is the hallmark of cognitive flexibility. This fluid way of thinking requires one to apply previously learned information to unfamiliar and more complex scenarios, where smaller, and likely more well-defined concepts, must be spontaneously and flexibly restructured and combined to meet rapidly changing situational demands brought about by the novel, complex scenario (7). In addition, cognitive flexibility requires portions of one concept to be used in conjunction with portions of

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Adding to the challenges of advanced knowledge acquisition is the inherent ill-structure of physiology. The term “ill-structured” does not imply that the field or domain of physiology is somehow disorganized or lacking structure. Quite the opposite is true. An ill-structured domain is one in which the information is inherently complex and contains patterns in which concepts that are used to solve problems are irregular (7). In physiology and other ill-structured domains, information is generally comprised of concepts where multiple inputs could contribute or influence a single outcome, yet a rigid sequence of events or chronicle of steps will not suffice to explain the outcome every time. Furthermore, outcomes cannot be reduced to one single interpretation, a fallacy known as a seductive reduction or a reductive bias (6), that will work every time under every condition due to the irregularities and novelties existing within ill-structured domains. However, having experienced mostly surface-level learning in previous courses predisposes students to thinking that a particular piece of information will always apply to every situation; for example, after learning that heart rate is increased by norepinephrine, they will answer nearly 100% of the time that an intravenous injection of norepinephrine should increase the heart rate. Due to baroreceptors, however, intravenous injection of norepinephrine actually decreases heart rate, which is a perfect example of why physiology is frequently an ill-structured domain. To succeed in the process of advanced knowledge acquisition when immersed within ill-structured domains, learners must attain a deeper understanding of content material, reason with it, and apply it flexibly in diverse contexts (7). In other words, learners must become more cognitively flexible to achieve advanced knowledge acquisition within an ill-structured domain.

Theoretical framework. This study was guided by the central tenets of the Cognitive Flexibility Theory. This theory focuses on the nature of teaching and learning within complex and ill-structured domains and stresses the importance of situation-dependent schema assembly, or use of previously learned concepts, instead of the mere retrieval of precompiled generic knowledge structures that are “monolithically superimposed on the concrete case at hand” (7). Furthermore, the Cognitive Flexibility Theory explains the advantages provided to students when taking an elaborative approach to learning new material, which includes thinking about how new information fits with what they currently know and how they can use the information in the future. This theory also explains the disadvantages of students relying on rote memorization, which is a type of surface-level learning that couples oversimplification of concepts with short-term recall. Rote memorization does not lead to long-term changes in a student’s cognitive architecture, nor does it improve students’ problem-solving skills (1). Perkins (5) describes rote memorization as a last resort, a way of coping, a method employed to pass a test without developing any real ideas, which leads only to partial and brittle understandings. Over time, rote memorization leads to the production of inert knowledge (5). Inert knowledge is information a student can recall under explicit situations but cannot retrieve or use for solving a problem that naturally occurs in the world around him or her, as the information was learned in a decontextualized setting (5, 8, 10).

Unfortunately, many students often experience success using a rote memorization approach within introductory courses, and, once these poor learning habits are cemented, they can become exceptionally difficult to dislodge. As predicted by the Cognitive Flexibility Theory, this will inevitably interfere with student success in intermediate and advanced courses, especially if these courses are within ill-structured domains.

Conceptual framework. Using the Cognitive Flexibility Theory as a guide, we focused on the relationship between students’ approaches to learning new material, prior knowledge levels, and success within an intermediate physiology course. It was hypothesized that students who prefer to take a more elaborative approach when learning new material will not only have higher levels of prior knowledge, giving them a better foundation on which to add new information, but will also attain higher scores on unit exams, yielding a greater level of overall success within this course. To evaluate these relationships, the following research questions (RQ) were examined:

RQ1: Does the predisposition for a certain approach to learning relate to the amount of information retained from previous science courses?

RQ2: Is there a relationship between a particular approach to learning new information within an intermediate undergraduate physiology course and success on unit exams?

Participants and recruitment. For this study, we recruited students from a large, intermediate level, undergraduate physiology course at a large Midwestern university at the beginning of the Spring 2016 and Fall 2016 semesters. The background and level of preparation varied widely in this population, as did academic and career goals. In addition, both science majors and non-science majors were represented in both semesters. All procedures and activities associated with this study were approved by our university’s Institutional Review Board. Statements of informed consent were given both in a written and verbal form, and students were told that they would receive a small amount of extra credit for participating. Students not wanting to participate in the study but still wanting to receive the small amount of extra credit were given the option of completing an alternative assignment.

METHODOLOGY

This study took place within an intermediate physiology course that was offered in the Spring of 2016 and again in the Fall of 2016. A total of 253 students were offered a chance to participate, 3 students dropped the course, and 8 additional students were removed from data analysis due to missing scores on at least one portion of data collection; thus a total of 242 students completed all components and were included in data analysis. Data collected and analyzed in this study consisted of scores from a prior knowledge assessment (PKA), responses to the Student’s Approaches to Learning (SAL) survey, and five unit exams that were given over the course of the semester. Extra credit, quizzes, and homework assignments were not included in data analysis. For ease of application in other courses, we have included in Fig. 1 an illustration of the experimental design of this study as it occurred over each 16-wk academic semester, including the use and timing of the components; however, this schedule could be altered based on the specifics of other institutions’ academic semesters.

The PKA was designed, refined, and validated by the researchers over the course of several semesters before being used in this study. The assessment, shown in Table 1, consisted of 10 multiple choice questions that were specifically designed to assess students’ background knowledge in topics pertinent to the intermediate physiology course and were verified to have been taught in the prerequisite
course. Each question on the PKA could have multiple correct answers; to receive full credit for each question, all correct answers had to be selected. This all-or-none approach reduced the likelihood of guessing and receiving an artificially inflated score. The PKA was administered on the first day of class before any content was delivered.

The SAL survey (3) is a validated instrument that assesses factors related to learning and achievement in math, reading, and science that are difficult to define in a course curriculum; for example, study habits and amount of mental effort a student is willing to expend when learning new information. The SAL asks students to indicate how much they agree with a statement by selecting one of five options, ranging from strongly disagree, which was given a numerical value of 1, to strongly agree, which was given a numerical value of 5, using a Likert-type scale. In addition to being subject specific, the questions on the SAL are organized into four main themes: self-regulated learning strategies, self-beliefs, motivation, and learning preferences. While all four of these themes were assessed with students, we removed questions related specifically to math and reading, concentrating only on questions related to learning science (APPENDIX A). Of the questions related to learning science, we were most interested in those that assessed self-regulated learning strategies (Table 2) to investigate how these specific strategies related to cognitive flexibility, or the ability to flexibly reason with and apply complex information, and academic success within an intermediate physiology course. Self-regulated learning strategies gauge how students approach new information presented to them in a formal learning environment and predicts their proclivity for taking one of two distinct approaches to learning: elaboration or memorization. We hypothesized that students with higher elaboration scores will also have higher PKA scores and higher unit exam averages.

To test this, responses from each student to questions about self-regulated learning strategies (Table 2) were summed, resulting in each student having an elaboration score and a memorization score. The memorization score was then subtracted from the elaboration score, giving each student a value termed the “SAL metric” that represented, on a scale of −16 to +16, their preference or propensity for these distinctly different approaches to learning. Because the lowest number that could be selected for any question on the SAL was 1, the SAL metric range was figured using the following formula: \[[(5 \times 4) – 4].\] A value of −16 indicated a very strong preference for memorization, and +16 represented a very strong preference for elaboration. This method of assigning one value to each student prevented the student from being counted twice during data analysis, as could happen with a simple correlation of student responses in which the student had both high and low numeric scores in response to SAL memorization or elaboration scores. SAL metric values ranged from −13 to +14 in our data set.

Five unit exams were given over the course of each semester; all were multiple choice in format and structured to assess the ability of students to answer basic, applied, and transfer questions. Each exam was worth 60 points and consisted of 30 multiple choice questions. Furthermore, each multiple choice question consisted of five possible answers, and more than one answer could be correct, requiring students to evaluate each possible answer independently and apply each possible answer to the question to gauge its applicability to the concept in the question. Partial credit was awarded, but, to receive full credit for a question, all correct answers had to be selected, and all incorrect answers not selected. This reduced the ability to receive a full amount of points based on guessing.

All analyses, as described in detail for each result below, were performed using IBM’s SPSS, version 23. Unless otherwise specified, levels of significance were set at \(P < 0.05.\)

RESULTS

RQ1: Does the predisposition for a certain approach to learning relate to the amount of information retained from previous science courses?

Preliminary analyses performed on the original sample of 253 students revealed the presence of 11 anomalous scores, such as missing data or outliers on the PKA; these were excluded from further analysis. A Pearson product-moment correlation was then performed after verifying all assumptions for using this statistical test had been met.

As shown in Fig. 2, there was a positive correlation between students’ preferences for certain approaches to learning, as represented by students’ SAL metrics, and prior knowledge levels, \(r(240) = 0.30, P = 0.00.\)

After collecting and analyzing data for RQ1, we determined that a student’s approach to learning does relate to the amount of information retained from previous science courses.

RQ2: Is there a relationship between a particular approach to learning new information within an intermediate undergraduate physiology course and success on unit exams?

A Pearson product-moment correlation was performed after verifying all assumptions for using this statistical test had been met.

As shown in Fig. 3, there was a positive correlation between certain approaches to learning, as represented by students’ SAL metrics, and exam scores, \(r(240) = 0.27, P = 0.00.\)

After collecting and analyzing data for RQ2, we determined that a student’s approach to learning new information within an intermediate undergraduate physiology course does relate to success on unit exams.

DISCUSSION

The main objective of this study was to examine the relationship between cognitive flexibility and advanced knowledge acquisition within an ill-structured domain, specifically physiology. It was hypothesized that students possessing a more evolved level of cognitive flexibility, meaning they relied on an elaborative approach when learning new material as opposed to a memorization approach, would achieve greater success within an undergraduate physiology course. The results of our analyses support our hypothesis.

The SAL instrument was chosen as a gauge of cognitive flexibility for this study. The SAL aims to measure how deeply
Table 1. Prior knowledge assessment

1. Choose any of the following that are correctly matched:
   a. Facilitated diffusion – Process whereby molecules can pass through a cell membrane; the only thing required for this movement is a concentration gradient.
   b. Simple diffusion – Process whereby molecules pass through a cell membrane to create a concentration gradient from one side of the cell membrane to the other.
   c. Primary active transport – Process whereby molecules are moved through a cell membrane against their concentration gradient, using ATP directly as a source of energy.
   d. Osmosis – Process whereby water diffuses from an area where there are more dissolved particles to an area where there are fewer dissolved particles.
   e. Secondary active transport – Process whereby molecules are moved through a cell membrane against their concentration gradient, using the concentration gradient of another molecule as a source of energy.

2. If a red blood cell is placed into a hypertonic solution of sodium chloride it could:
   a. Shrink due to osmosis.
   b. Swell due to osmosis.
   c. Shrink due to diffusion.
   d. Swell due to diffusion.
   e. Die due to inability to regulate metabolic processes.

3. The movement of water from the blood and into a cell:
   a. Is dictated by the tonicity of the cell.
   b. Occurs more efficiently if membrane proteins such as aquaporins are present.
   c. Will slow if too much Na⁺ is present within the cell’s cytoplasm.
   d. Could be disrupted, if edema developed in the interstitial space.
   e. Is dependent on the number of pumps within the cell’s membrane that can actively transport water into the cell.

4. Glucose:
   a. Is regulated by insulin.
   b. Cannot be used by the brain for production of ATP.
   c. Is covalently linked to fructose to form sucrose.
   d. Is composed of a six-carbon ring structure that also includes oxygen as a component of the ring.
   e. Cannot be synthesized by the body, so it must be obtained from the diet.

5. Insulin:
   a. Is secreted by the pituitary gland in response to high blood glucose.
   b. Should cause a decrease in blood glucose, if all negative feedback pathways are working normally.
   c. Could cause excess glucose in the blood to be converted to fat and stored within adipose tissue.
   d. Should increase the amount of circulating rather than stored energy and thus would be elevated in those people who are undergoing high-stress conditions.
   e. Is normally required by skeletal muscle cells to absorb glucose from the surroundings.

6. ATP:
   a. Stands for Adenosine Triphosphate.
   b. Is broken down by enzymes such that ATP → ADP + Pᵢ + energy.
   c. Is produced primarily in the liver.
   d. Is used to provide energy for muscle contractions.
   e. Is used by the brain in large quantities to absorb glucose.

7. The production of ATP:
   a. Can only occur in the presence of oxygen.
   b. Requires catabolic and anabolic reactions.
   c. Can only occur if a cell has adequate amounts of glucose.
   d. Always yields byproducts such as CO₂ and H⁺.
   e. Can occur via a process known as substrate level phosphorylation.

8. Cell membrane proteins:
   a. Can be upregulated or downregulated by the cell.
   b. Are fixed or set for the duration of the cell’s life.
   c. Require transcription and translation before being inserted into the membrane.
   d. Allow the cell to receive and respond to messages from other cells.
   e. Are the same within every cell of an organism’s body.

9. Negative feedback is a crucial component of homeostasis because:
   a. It allows the body to anticipate changes and prepare for what is about to happen.
   b. It amplifies or increases the deviation of a regulated physiological variable away from its set point.
   c. It returns a regulated physiological variable back to an acceptable range after its deviation has been detected.
   d. It prevents regulated physiological variables from ever deviating outside of their strict set point.
   e. It requires conscious regulation by the brain and thus keeps the organism aware of its physiological condition at all times.

10. Which of the following is a physiologically correct example of negative feedback to help keep body temperature at its normal set point when environmental conditions are much colder than body temperature?
   a. Increased activity of insulin to catabolize fat tissues.
   b. Increased skeletal muscle activity to liberate energy in the form of heat as ATP is broken down.
   c. Increased blood flow to the skin.
   d. Increased piloerection to improve insulation at the surface of the skin.
   e. Decreased release of hormones that stimulate hunger sensations to save energy by reducing digestive processes.

The prior knowledge assessment provided insight into the level of background knowledge students possessed on the first day of class and covered content known to have been taught in a prerequisite course. Correct answers are shown in bold.
Questions from the self-regulated learning strategies portion of the SAL gauged students’ tendencies to rely on memorization or elaboration strategies when learning new information. Memorization includes reciting information verbatim until it is stored in memory with little or no further processing. Elaboration includes construction and integration of previously learned information with new information and transfer of this combined knowledge to a novel problem.

<table>
<thead>
<tr>
<th>SAL Factor: Memorization</th>
<th>SAL Factor: Elaboration</th>
</tr>
</thead>
<tbody>
<tr>
<td>When I study, I try to memorize everything that might be covered.</td>
<td>When I study, I try to relate new material to things I have learned in other subjects.</td>
</tr>
<tr>
<td>When I study, I memorize as much as possible.</td>
<td>When I study, I figure out how the information might be useful in the real world.</td>
</tr>
<tr>
<td>When I study, I memorize all new material so that I can recite it.</td>
<td>When I study, I try to understand the material better by relating it to things I already know.</td>
</tr>
<tr>
<td>When I study, I practice by saying the material to myself over and over.</td>
<td>When I study, I figure out how the material fits in with what I have already learned.</td>
</tr>
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Fig. 2. Results of a Pearson’s correlation between certain approaches to learning (SAL metric) and scores on the prior knowledge assessment (PKA). The all-or-none grading rules used for each question on the PKA resulted in student scores being discrete variables; thus each data point represents multiple students. Distribution of scores was skewed, such that 80 students scored 0 points, 90 students scored 1 point, 40 students scored 2 points, 16 students scored 3 points, 8 students scored 4 points, and 8 students scored 5 points. Students scoring 6 points or above were removed from analysis, as they represented outliers.
the skewed distribution of scores, it is possible that the assessment was too difficult, given the comparatively small number of students scoring above a 3, and this could have influenced our results. Refining the PKA and verifying each individual question with an Item Difficulty Index would have been advantageous. However, the finding that there is a relationship between a student’s approach to learning and his or her prior knowledge, as measured by this difficult assessment, is still noteworthy for several reasons. First and foremost, the finding that a student’s approach to learning has any influence on the amount of knowledge they are capable of amassing during their undergraduate years is an important consideration when thinking about the lasting impacts introductory and intermediate level courses can have on students and truly how critical the construction of foundational knowledge can be. For example, if, within introductory courses, students are exposed to and encouraged to take an elaborative approach to learning, the additional amount of information they may be able to retain and use in the future could possibly compound with every passing semester, potentially leading to substantial improvements by the time they matriculate into professional schools or begin their careers. This is in stark contrast to what happens if students begin with a memorization approach during their introductory courses and continue with this approach: their learning potential continues to erode, first by having less prior knowledge available for every subsequent course, which could likely lead to poorer performances on exams and less overall academic success.

Second, unlike many factors that impact a student’s success within a physiology course or courses that may be more

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### Table 3. Implementing the Cognitive Flexibility Theory

<table>
<thead>
<tr>
<th>Cognitive Flexibility Theory Principles</th>
<th>Suggestions for Implementation</th>
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<tbody>
<tr>
<td>Reduce linear presentation and compartmentalization of information; use multiple representations when presenting information.</td>
<td>Present and discuss information using a weblike format, perhaps with concept maps, which allow for the visualization of relationship and interconnectedness of concepts.</td>
</tr>
<tr>
<td>Encourage construction of interconnected schema by presenting concepts using different examples, revisit concepts using a variety of different scenarios.</td>
<td>Select and discuss diseases related to a concept and explain how the concept contributed to or resulted from the disease; crisscross the landscape by examining anomalies.</td>
</tr>
<tr>
<td>Avoid oversimplification, be aware of seductive reductions where complex concepts are distilled to oversimplified components. Transfer parts of a concept to new problem or scenario.</td>
<td>Avoid the use of mnemonics, metaphors, and analogies; these tend to encourage oversimplified thought processes. Use a concept to explore the issues with which a patient presents, perhaps as part of a case study.</td>
</tr>
<tr>
<td>Encourage independent exploration of concepts.</td>
<td>Ask students to find a short video, podcast, or even popular magazine article related to the concept and explain how it relates.</td>
</tr>
<tr>
<td>Provide opportunities to apply previous knowledge to new situations.</td>
<td>Apply previous unit or chapter information to new unit or chapter to highlight interconnectedness of body systems; ask questions that require the use of previously learned information to solve new problem.</td>
</tr>
<tr>
<td>Require students to go beyond simple reproduction and recall of information on exams.</td>
<td>Incorporate applied and transfer type questions; avoid questions that can be solved with recognition and recall.</td>
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</tbody>
</table>
difficult to change, such as extrinsic motivation, self-efficacy, and preference for group work, to name a few, a student’s approach to learning new material likely can be changed, refined, and even improved on if the benefits of doing so are specifically highlighted. Results from this study provide the initial support for the need to accomplish this; furthermore, the earlier these improvements to learning occur, the more successful the student will likely be within his or her academic career and even after graduation.

It is important to note that there were a few students who appeared to have a strong preference for memorization yet achieved high scores on the PKA and unit exams. However, this was not the general trend. While we do not yet know why this may have happened, it is possible that administering the SAL only one time during the semester, specifically on the first day of class, provided only a snap-shot of students’ learning preferences. Perhaps students identifying as having a strong propensity for memorization began to see the error of their ways and adopted a more elaborative approach over the semester, but we did not capture this change. Thus only gathering SAL scores one time could have caused us to mistakenly identify some students as memorizers and assume that this preference lasted for the duration of the semester. Administering the SAL again during the middle and end of the course to see how students’ approaches to learning might have changed as they were exposed to the ill-structured domain of physiology would have improved this study.

The results of this study support the notion that an elaborative approach to learning is beneficial for students in several ways. However, to help students progress with an elaborative approach to learning, our approach as educators likely needs to change as well. Many common methods of instruction and familiar pedagogical tools are often not designed to encourage cognitive flexibility, as these rarely focus on improving students’ elaborative approaches to learning. Instead, these methods often rely on linear media, such as textbooks and lectures using slideshows, which likely and unknowingly foster or allow students to take a memorization approach (4) and encourage the formation of rigid scripts that can only be used when activated by a similar scenario in the future (2). Kirschner et al. (1) perhaps best explain the reason for this relationship by describing how memorizing large chunks of information overpowers the working memory of learners and reduces the amount of information that is stored, retrievable, and usable in the future. As a result of memorization, the only permanent change that is likely to occur is an increase in inert knowledge, which does not help in future coursework or in a career, although it can, unfortunately, serve beneficial roles in introductory courses where these habits are likely cemented (1, 6). Even more unfortunate is the possibility that prior knowledge constructed via memorization may actually reduce new learning required for deeper understanding.

In contrast to curricular methods and tools that present information linearly are those that encourage nonlinear learning, where content is revisited using multiple contexts, crisscrossing the learning domain or landscape, with each pass bringing out additional aspects of the content’s complexity, which would likely be missed in a single pass of linear coverage. This is the heart of the Cognitive Flexibility Theory, which explains the need to increase students’ abilities to crisscross a learning domain, using previously learned information to appreciate and comprehend the complexities of their new landscape via elaboration. In stark opposition to rote memorization and oversimplification of concepts, elaboration helps improve a student’s ability to comprehend or interpret information that has not yet been seen and improves the knowledge acquired from instruction, allowing it to serve as a more effective background to support the comprehension of advanced concepts (7). Because the often ill-structured field of physiology requires the flexible use of knowledge and requires the consideration of a diverse set of circumstances, the reliance on a small number of rigidly prepackaged schemata will not suffice; thus neither will the reliance on memorization-based instructional methods. We believe this could explain why students who take a more elaborative approach to learning experienced greater academic success within our intermediate physiology course: elaborative learning strategies encouraged transfer, which led to enriched schema construction and a broader base from which to draw on when attempting to learn and understand complex material. However, to improve students’ elaborative skills when learning, we believe it must be modeled in our teaching. Table 3 provides suggestions for implementing the core principles of the Cognitive Flexibility Theory into an undergraduate physiology course, as well as examples illustrating how to improve elaborative learning strategies and discourage memorization learning strategies.

We believe the next step in continuing to improve on this area of student development is the creation of pedagogical tools that are designed for the express purpose of improving students’ elaborative approaches to learning and thus their level of cognitive flexibility. These tools could be very useful for both undergraduate and professional level students, especially when considering the issues that a 21st century workforce will encounter in the form of novel, complex, and unstructured problems (9), all of which require a heightened level of cognitive flexibility.

APPENDIX A: COMPLETE STUDENT LEARNING APPROACHES SURVEY

There are no “right” or “wrong” answers. All that matters is your opinion. Think about how well each statement describes you and your approach toward this course.

For each question in Table A1, use the scantron and fill in the following:

A if you strongly disagree with the statement.
B if you disagree with the statement.
C if you neither agree nor disagree with the statement.
D if you agree with the statement.
E if you strongly agree with the statement.

DISCLOSURES

No conflicts of interest, financial or otherwise, are declared by the author(s).

AUTHOR CONTRIBUTIONS


REFERENCES

1. Kirschner PA, Sweller J, Clark RE. Why minimal guidance during instruction does not work: An analysis of the failure of constructivist,
1. When I study, I force myself to check periodically to see if I remember what I have learned. A B C D E
2. When I study, I start by figuring out exactly what I need to learn. A B C D E
3. When I study, I try to figure out which concepts I still don’t really understand. A B C D E
4. When I study, I make sure that I remember the most important things. A B C D E
5. When I study, and I don’t understand something, I look for additional information to clarify this. A B C D E
6. When I study, I try to memorize everything that might be covered. A B C D E
7. When I study, I memorize as much as possible. A B C D E
8. When I study, I memorize all new material so that I can recite it. A B C D E
9. When I study, I practice by saying the material to myself over and over. A B C D E
10. When I study, I try to relate new material to things I have learned in other subjects. A B C D E
11. When I study, I figure out how the information might be useful in the real world. A B C D E
12. When I study, I try to understand the material better by relating it to things I already know. A B C D E
13. When I study, I figure out how the material fits in with what I have already learned. A B C D E
14. When studying, I keep working, even if the material is difficult. A B C D E
15. I’m certain I can understand the most difficult material presented in the lecture e-text. A B C D E
16. I’m confident I can understand the most complex material in this course. A B C D E
17. I’m confident I can do an excellent job on assignments and tests in lecture. A B C D E
18. I’m certain I can master the basic skills being taught. A B C D E
19. When I sit myself down to learn something really difficult in this course, I can learn it. A B C D E
20. If I decide not to get any bad grades, I can really do it. A B C D E
21. I like to work with other students. A B C D E
22. I learn most when I work with other students. A B C D E
23. I do my best work when I work with other students. A B C D E
24. I like to help other people do well in a group. A B C D E
25. In a course like this, I like to try to be better than other students. A B C D E
26. Trying to be better than others makes me work well. A B C D E
27. I learn faster if I’m trying to do better than the others. A B C D E
28. I usually receive good grades in science courses. A B C D E
29. Science is one of my best subjects in college. A B C D E
30. I have always done well in college science courses. A B C D E

Questions 6–13 were used for data analysis in this study, as they specifically measured elaboration and memorization approaches.