A novel educational tool helps teach intestinal absorption in physiology

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Abstract

A novel educational tool helps teach intestinal absorption in physiology—We have designed an interesting educational tool to help sophomores learn intestinal absorption in physiology course. In the study group (2019), 51 sophomores from biomedical engineering were encouraged to learn the intestinal absorption knowledge through reading materials and group discussion. Then, using the form of flipped class, they stepped on the podium and simulated and explained the absorption processes with designed paper props as educational tool. In contrast, the control group (2018), 52 sophomores from the same specialty had taken the same professional courses before. The result of theoretical test showed the average score in the study group was higher than that in the control group. The questionnaire analysis showed the positive role of the educational tool in their learning efficacy. To sum up, using our tool has achieved better teaching effects than the traditional lecture.

INTRODUCTION

In physiology teaching, intestinal absorption involves lots of knowledge of transmembrane transport, which is difficult to understand and remember (1). Educational tools have been proven beneficial and fun in teaching practice, which can encourage thinking and reasoning and group discussion, enhance problem-solving skills, and strengthen understanding and memory of knowledge (2, 3). Therefore, we designed a simple and interesting educational tool to help learn intestinal absorption physiology: using the form of flipped class, we encouraged students to find out the intestinal absorption knowledge of nutrients through reading materials and group discussion and then step on the podium, and simulate and explain the absorption processes with paper props in detailed and orderly ways.

To know about whether the tool helped students in learning, we designed a test paper covering the contents of intestinal absorption. Fifty-one sophomores who only participated in traditional lectures in 2018, during which the same teacher gave lectures with the aid of PowerPoint slides, were taken as the control group. Fifty-two sophomores who participated in the study group (2019), 51 sophomores from biomedical engineering were encouraged to learn the intestinal absorption knowledge through reading materials and group discussion. Then, using the form of flipped class, they stepped on the podium and simulated and explained the absorption processes with designed paper props as educational tool. In contrast, the control group (2018), 52 sophomores from the same specialty had taken the same professional courses before. The result of theoretical test showed the average score in the study group was higher than that in the control group. The questionnaire analysis showed the positive role of the educational tool in their learning efficacy. To sum up, using our tool has achieved better teaching effects than the traditional lecture.

METHODOLOGY

Preparation

The educational study was approved by the department. An educational tool was administered to 51 sophomores from biomedical engineering in the physiology course in 2019. All students agreed to participate in the study. We randomly grouped students according to the name list. As a result, we had 5 groups with 10–11 students per group. Meanwhile, our teaching team consisted of an associate teacher and two assistants from senior classes. During our class, the teacher supervised the overall process and the theoretical knowledge involved, while two assistants helped to coordinate the presentation order.

The main props of our study were specially designed cards with different colors, shapes, and contents (see Supplementary Fig. S1 at https://doi.org/10.6084/m9.figshare.13089836.v1). They included three types as follows: 1) cards representing 11 nutrients; 2) cards representing transport structures, including carriers, channels, pumps, symporters, antiporters, and others; and 3) cards representing auxiliary substances and different forms of nutrients. Each set of cards consisted of the above three types of cards and five blank cards for students to draw structures or substances that were not on the list. Five sets of cards were prepared for each of five groups. We also prepared an additional set of cards for use in the demonstration by the teacher.

In addition, we also prepared five blank posters and five posters painted with the outline of a small intestine...
epithelial cell, which would be used as backgrounds in the class. Additional resources were blank paper, markers, scissors, tape, etc.

**Process of the Study**

Before the beginning of the class, an assistant taped the five blank posters to the blackboard. Each student group was allocated one poster. Each group was asked to learn relevant materials and discuss: which structures can help expand the absorption area of the small intestine? Then, each group selected a student to draw the schematic diagram of these structures (folds, villi, and microvilli) on the poster. Once they finished, the teacher chose the group with the highest degree of completion and asked the group to explain the schematic diagram to the whole class. Other groups corrected mistakes and supplemented relevant knowledge. Then, the teacher summarized the core knowledge points: folds, villi, and microvilli increase the absorption area of the small intestine by ~600 times over the internal surface area of a simple cylinder of the same length to 200–250 square meters.

After the drawing step, an assistant replaced the drawing posters with five posters painted with the outline of a small intestine epithelial cell. Each group was given one poster. This was the background for the later presentation. One schematic diagram of students’ drawing and the epithelial cell is shown in Fig. 2.

An assistant then handed out the props to students. Each group got a complete set of cards. The cards provided were gummed so that students could easily paste them onto the blackboard. Other tools such as blank paper and markers were also distributed.

The teacher encouraged students to get familiar with the props, and introduced the rules: 1) paste the cards representing transport structures on the brush border membrane or the basolateral membrane of the epithelial cell; and 2) show, move, or replace the cards representing nutrients, auxiliary substances, and different forms in the transport process to simulate the absorption of a specific substance across the small intestine.

At the beginning, the absorption process of vitamin B12 (VB12) was demonstrated by an assistant on the blackboard in front of the students: in the upper part of the small intestine, VB12 binds to the intrinsic factor (IF). Upon getting to the ileum, the VB12-IF complex is transported into intestinal epithelial cells through ligand-receptor binding mediated endocytosis. After that, IF is decomposed in lysosomes, and VB12 is transported out of the cell through multidrug-resistant associated protein-1 (MRP1). Then, after its absorption into the blood, VB12 is involved in the erythrocyte maturation process. If IF is absent because of atrophic gastritis or subtotal gastrectomy, the absorption of VB12 will meet obstacles which will result in megaloblastic anemia. The precise situation is shown in Fig. 3. After the demonstration, the assistant tore off the cards and restored the blank epithelial cell to the students.

After the demonstration, the assistants continued to elaborate on what students needed to explain 1) where nutrients are mainly absorbed in the small intestine; 2) which route does the absorption of each substance occur, transcellular pathway or paracellular pathway; and 3) focus on the details of the transcellular pathway: i) is it absorbed via simple diffusion, facilitated diffusion, primary active transport, secondary active transport, exocytosis, endocytosis, or other and what is it by; and ii) what carriers, channels, ion pumps, symporters, antiporters, auxiliary substances and absorption forms are involved? Students’ answers did not have to be strictly following the above aspects, but could be adjusted according to the absorption characteristics of specific substances. We hoped to help students learn about intestinal absorption by grasping these key points shown in Table 1.

Students made presentations in two rounds. In the first round, they were invited to explain the small intestinal absorption of the first five nutrients in Table 1. In the second round, the other five nutrients should be explained. Each round consisted of three sections: 1) **Section A**: each group learned about the intestinal absorption of the given five nutrients by themselves.
We required each student in a group to fully participate in the searching and discussion.

2) Section B: representatives from five groups drew lots to decide which nutrient each group would present on the podium. Then, all students made in-group preparation. We recommended that one student from each group could be chosen to paste and move cards and two students could be selected for explanation and supplement.

3) Section C: each group took turns to make presentations according to the given order. After the explanation, other students freely made supplements and asked questions, which encouraged the students on the podium to explain and answer. Then, an assistant summarized the absorption process to help students sort out their thoughts and deepen their memory. The teacher also made supplements and expanded relevant knowledge.

The above sections were the highlight of the whole study, during which we put forward strict requirements for students. The positions and directions of transport structures and the positions of different forms of one substance tended to cause the mistakes. For students who did not explain clearly, we guided them to correct themselves. In terms of expression, students were encouraged to be clear and lively. During the explanation of a group, students of other groups should listen carefully, think, and ask questions actively. To help students understand and remember, we encouraged them to take notes in time, or to organize their thoughts by drawing mind maps or others. Students’ achievements are shown in Figs. 4 and 5.

Evaluation

As this was the first time that this new type of teaching method was adopted, the teacher affirmed the effectiveness of students’ teamwork and praised students’ expression and logical thinking. Then, the students finished the same theoretical test on the knowledge of small intestinal absorption as those in the control group in 2018, which represented a reasonable degree of difficulty, and wholly consisted of single-choice questions.

At the end of the class, students filled out feedback questionnaires anonymously. The questions on the questionnaire along with students’ main choices are shown in Table 2. Questions 1, 2, and 3 are about the effectiveness of our educational tool for learning. Questions 4, 5, 6, and 7 are about the study design, which evaluate its science, interest, difficulty and design of props. Questions 8, 9, and 10 evaluate the team’s learning. Question 11 asks about the overall recommendation for our educational tool. With reference to the commonly used Kirkpatrick Model, a Likert scale (ranging from strongly disagree, disagree, neutral, agree, and strongly agree) (2, 3, 6~8) was applied to measure students’ opinions about our educational tool (9). In addition, there is a subjective question asking students for their opinions on this tool. We hoped to collect students’ suggestions from multiple dimensions, so as to further optimize the study design and continuously improve the class quality.

Statistical Analyses

The scores of all students who participated in the test were recorded. A completely random design t test was used to test whether there were differences between the two groups. The significance level was 0.05, and the analyses were performed in SPSS 20.0.

RESULTS

New Educational Tool Improved Students’ Test Performance

The test’s full mark was 100 points. The average total score of the study group (51 students in 2019) was 80.78 ± 14.40, while that of the control group (52 students in 2018) was 58.89 ± 16.08. The total score of students in the study group was higher than that in the control group (P = 1.2936 × 10^-10).

Subjective Evaluation from Study Group

A total of 42 questionnaires were collected from the study group students anonymously. We performed statistics of the five-level scores on the questionnaire. The main results are
Table 1. **Key points of nutrient absorption**

| Nutrients                          | Key Points                                                                                                                                 |
|-----------------------------------|------------------------------------------------------------------------------------------------------------------------------------------|
| **Water**                         | 1) It is transported passively through transcellular pathway (osmosis/by aquaporin water channels) and paracellular pathway.  
2) The osmotic pressure gradient between two sides of the mucosa generated by the absorption of various solutes (especially NaCl) is the major driving force for water absorption.  
3) In the duodenum and upper jejunum, the amount of water moving from the intestinal lumen into the blood and water moving from the blood into the intestinal lumen are both large. Thus the change in liquid in the upper part of the intestinal lumen is not obvious. In the ileum, more fluid leaves the lumen than enters. Thus the volume of liquid in the intestine is greatly reduced. |
| **Glucose**                       | 1) It is mainly absorbed in the upper part of the small intestine (duodenum and jejunum).  
2) Its entry into the cell is mainly through secondary active transport: The Na\(^{+}\)-glucose cotransporter on the brush border transports 1 glucose and 2 Na\(^{+}\) into the intestinal lumen into the cell simultaneously. Its primary power is the Na\(^{+}\)-K\(^{+}\) pump on the basolateral membrane which actively pumps 3 Na\(^{+}\) out to the intestinal fluid while adding 2 K\(^{+}\) into the cytoplasm to establish the Na\(^{+}\) gradient.  
3) It leaves the cell mainly by facilitated diffusion: the non-Na\(^{+}\) dependent glucose transporter (GLUT2) in the basolateral membrane transports glucose from the cytoplasm into the interstitial fluid. Then, the glucose is absorbed into blood. (Expanding knowledge: recent evidence suggests that a significant amount of glucose crosses the epithelium through the leaky tight junctions between epithelial cells.) |
| **Fructose**                      | 1) Its entry into the cell is mainly via facilitated diffusion through non-Na\(^{+}\)-dependent glucose transporter (GLUT5).  
2) The intracellular conversion of fructose into glucose and lactic acid maintains its low intracellular concentration, aiding its continued absorption via facilitated diffusion from the lumen.  
3) The glucose that was transformed and the remaining intact fructose leave the cell by facilitated diffusion through the glucose transporter (GLUT2) on the basolateral membrane. |
| **Monoglyceride and long-chain fatty acid** | 1) Monoglyceride and long-chain fatty acid are carried in the interior of water-soluble mixed micelles, which are constituted by bile salts and other bile constituents, to the luminal surfaces of the small intestine epithelial cells. Then they are released from the mixed micelles and passively diffuse through the lipid bilayer.  
2) After entering the cell, most of them are resynthesized into triglyceride in the endoplasmic reticulum, which aggregates and is coated with a layer of lipoprotein to form water-soluble chylomicrons.  
3) Chylomicrons are released into interstitial fluid by exocytosis and diffuse into lymphatic vessels. (Expanding knowledge: short and medium chain fatty acids are water-soluble and can be absorbed directly into the blood instead of the lymphatic circulation. Protein-dependent mechanisms involving fatty acid translocase, fatty acid transport proteins and so on play a role in the uptake of long-chain fatty acid as well.) |
| **Dipeptide and tripeptide**      | 1) Its entry into the cell is mainly via secondary active transport through H\(^{+}\)-coupled oligopeptide transporter: H\(^{+}\) is transported from the lumen into the cell down its concentration gradient, and di- or tripeptide is transported into the cell against its concentration gradient. The primary driving force is the H\(^{+}\)-concentration gradient generated by Na\(^{+}\)-H\(^{+}\) exchange.  
2) Oligopeptides (di- and tripeptides) are hydrolyzed into amino acids by oligopeptidases in the cytoplasm.  
3) Amino acids leave the cell through facilitated diffusion, Na\(^{+}\)/Cl\(^{-}\)/H\(^{+}\)-dependent transport, etc. (Expanding knowledge: cooked proteins are easily digested because of denaturation and are quickly absorbed in the duodenum and proximal jejunum. Uncooked proteins are not absorbed until they reach the ileum.) |
| **Sodium**                        | It is absorbed via secondary active transport, with the primary driving force being the Na\(^{+}\)-K\(^{+}\) pump on the basolateral membrane. Na\(^{+}\)-K\(^{+}\) pump activity causes intracellular low sodium. Meanwhile, the potential of epithelial cells is about 40 mV lower than that in the intestinal lumen. Therefore, Na\(^{+}\) enters cells down its electrochemical gradient through epithelial Na\(^{+}\) channels (ENaCs), Na\(^{+}\)-glucose cotransporters, Na\(^{+}\)-amino acid symporters, Na\(^{+}\)-Cl\(^{-}\) symporters, Na\(^{+}\)-H\(^{+}\) exchangers, etc. It leaves cells through Na\(^{+}\)-K\(^{+}\) pumps on the basolateral membrane, and then enters the bloodstream. (Expanding knowledge: Na\(^{+}\) can be absorbed via passive diffusion through tight junctions as well.) |
| **Iron**                          | 1) Its entry into the cell mainly occurs through the Fe\(^{3+}\)-H\(^{+}\) cotransporter, as well as the divalent metal transporter 1 (DMT1) on the luminal membrane of epithelial cells, which is secondary active transport.  
2) In the cell, most of the Fe\(^{3+}\) is oxidized to Fe\(^{2+}\) and binds with the intracellular apoferitin to form ferritin, which is stored and released slowly into the blood.  
3) Ferroportin/FPN1 on the basolateral membrane transports a small amount of inorganic iron out of cells and into the bloodstream.  
4) The major absorption site of iron is the upper part of the small intestine. Fe\(^{2+}\) is more easily absorbed than Fe\(^{3+}\). Vitamin C can convert Fe\(^{3+}\) to Fe\(^{2+}\), thus promoting the absorption of iron. Gastric acid also promotes iron absorption. Its absorption depends on the body’s need. |
| **Calcium**                       | 1) The duodenum is the main site of active Ca\(^{2+}\) absorption by the transcellular pathway. All segments of the small intestine can passively absorb Ca\(^{2+}\) through the paracellular pathway.  
2) In the transcellular pathway, i) Ca\(^{2+}\) enters the epithelial cell through the calcium channel on the brush border down its electrochemical gradient; ii) in the cytoplasm, Ca\(^{2+}\) quickly binds to the calbindin to maintain a low level of cytoplasmic Ca\(^{2+}\) concentration, to avoid disrupting the cell signal transduction and other functions; and iii) at the basolateral membrane, Ca\(^{2+}\) bound to calbindin is released and leaves the cell through the calcium pump and the Na\(^{+}\)-Ca\(^{2+}\) exchanger.  
3) The principal factors affecting Ca\(^{2+}\) absorption are vitamin D and the body’s calcium requirements. (Continued)
shown in Table 2. As can be seen, the help in learning, the science and interest of the study design, the difficulty of the knowledge points, the aesthetics of props, the group learning efficacy, and the overall recommendation of the study were all recognized as helpful by most students.

### DISCUSSION

Intestinal absorption may be tedious new information and hard to remember for undergraduate students who have no clinical experience (1). Our educational tool aims at making improvements to teach absorption. The results indicated that the use of this tool enhanced students’ learning.

In our class, the first part checked students’ basic knowledge of the structural basis of the intestinal mucosa to absorb nutrients, which was fundamental for further practice. Drawing can intuitively reflect the degree of students’ understanding. Considering the significance of prior knowledge, we should pay attention to the intuitive ideas that students bring to the class, which will influence the guidance we will provide and the requirements for students later (10).

The second part is the highlight of our design. We adopted the form of “flipped class” and invited students as speakers to step up to the classroom podium to introduce their understanding and opinions to other students. It is a kind way of having students teach each other. Compared with traditional classes, it makes students protagonists and provides them with higher participation in class. Meanwhile, students are granted the responsibility of clarifying knowledge. Thus they can spontaneously mobilize the learning initiative in the preparation process, to complete the task better.

In terms of knowledge, with rapid lectures students passively accept knowledge. The amount of knowledge absorbed cannot be controlled by teachers (11). However, in our class, the clarity of explanation must be based on a more complete understanding. In addition, the process of explaining and being asked can further help students deepen and sort out their thoughts. Questions and answers can also help expand their knowledge. We are gratified by students’ feedback on the first three questions of the questionnaire: both the overall evaluation of the educational tool’s help in learning, and the subitem evaluation of colorful cognition and logical thinking, have received positive opinions from more than 70% of students. This is in line with the learning improvements shown by test results: when the same test questions were used to examine students’ mastery levels, the average total score of study group students was more than 20 points higher than that of control group students.

According to Bloom’s Taxonomy of educational objectives revised by Lorin Anderson et al. (15), **question 5**, whose accuracy did not show significant improvement, belongs to the category of “remembering” at the first level (view the test questions related with absorption physiology and their classification on Bloom’s Taxonomy; see Supplementary Table S1. at https://doi.org/10.6084/m9.figshare.13106783.v1). However, the progress of the students participating in our study was more reflected in high levels of “understanding,” “applying,” “analyzing,” and “creating,” which could be recognized because they independ-

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**Table 1.— Continued**

| Nutrients       | Key Points                                                                                                                                 |
|-----------------|---------------------------------------------------------------------------------------------------------------------------------------------|
| Chloride        | $\text{Cl}^-$ is absorbed via: 1) paracellular (passive) pathway, which is predominant in the small intestinal epithelium and depends on the transmural potential difference and downhill $\text{Cl}^-$ gradient; 2) transcellular pathway, through the $\text{Na}^+-$-$\text{Cl}^-$ symporter, the $\text{Cl}^-\text{HCO}_3^-$ exchanger, etc. $\text{Cl}^-$ generally follows $\text{Na}^+$ to maintain electroneutrality. |
| Vitamin E       | Similar to the decomposition products of fat, vitamin E is absorbed passively across the intestinal mucosa, incorporated into micelles, followed by incorporation into chylomicrons, with eventual transfer into the lymphatics. |

This table is based on Refs. 4, 5.

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**Figure 4.** These are students’ achievements during the first round. The dotted line with arrows indicates the transport process, which is the direction in which students move the cards. As for theoretical knowledge, there are many transporters of amino acids on the basolateral membrane but restricted by the conditions, only the amino acid carrier and $\text{Na}^+-$-amino acid symporter are given. At the end of round 1, cards were torn off and the blank cells were reserved for round 2.
ently acquired knowledge, and transformed it into logical demonstration and explanation (7). Meanwhile, according to Learning Pyramid Theory, teaching others is the learning method with the highest retention rate of the learning contents of 90%, which was the main method used in our educational study (12). Discussion groups and practicing by doing, which both have a retention rate of over 50% of the learning contents in the Learning Pyramid, are also reflected in our study.

The design of group cooperation can help students exercise their ability of labor division and cooperation: On the one hand, efficient group work requires reasonable decomposition of tasks, while, on the other hand, the sense of collective honor promotes mutual help among students in a group. By giving students free organizational space, peer pressure and peer education can play better roles (6, 13). To our pleasure, the questionnaire results have presented that the questions related to team cooperation have the highest recognition among all questions.

Some students thought the traditional teaching mode, in which teachers gave lectures and students passively received,

![Figure 5](https://advan.physiology.org/content/15/3/464/fig/5)

**Figure 5.** These are students’ achievements during the second round. Similar to round 1, the dotted line with arrows indicates the transport process. As for theoretical knowledge, there are many transporters of sodium, but only examples of Na⁺ channel, Na⁺-Cl⁻ symporter, and Na⁺-H⁺ exchanger are given. Transport mechanisms of coupling sodium with glucose, amino acid, and other nutrients are also very important. The same goes for calcium. Moreover, the absorption of chloride is mainly through the paracellular pathway. Therefore, chloride transporters are drawn in the figure but are not marked with dotted line. The absorption of fat-soluble vitamin E is similar to that of fat decomposition products, which has been described in detail in the first round and is shown here briefly.

| Questions | Strongly Agree: Number (Percentage) | Agree: Number (Percentage) |
|-----------|-------------------------------------|-----------------------------|
| 1. The educational tool can help you better understand and master the physiology of intestinal absorption. | 14 (33.33%) | 18 (42.86%) |
| 2. The educational tool can help you gain more vivid cognition of intestinal absorption. | 20 (47.62%) | 12 (28.57%) |
| 3. The educational tool can lead you to think and summarize logically. | 19 (45.24%) | 11 (26.19%) |
| 4. Links between different parts are designed reasonably, and the time is arranged properly. | 14 (33.33%) | 16 (38.10%) |
| 5. Knowledge that the class covers is of moderate difficulty. | 17 (40.48%) | 13 (30.95%) |
| 6. The educational tool is interesting. | 19 (45.24%) | 10 (23.81%) |
| 7. The props are designed beautifully and appropriately and have played a good learning aid. | 21 (50.00%) | 13 (30.95%) |
| 8. The classmates in your group held fine learning attitude and enthusiasm. | 20 (47.62%) | 15 (35.71%) |
| 9. The classmates in your group interacted well with each other, assisted each other, and exerted your strengths. | 18 (42.86%) | 18 (42.96%) |
| 10. The group discussion was organized and effective. | 17 (40.48%) | 16 (38.10%) |
| 11. You are willing to recommend other students learning intestinal absorption physiology to enhance their learning through this way. | 22 (52.38%) | 12 (28.57%) |
was more “efficient” than team-based learning. However, although the traditional teaching mode allows students to receive more knowledge, its efficiency of knowledge transformation is far lower. Team-based learning enables students to make personal sense of the knowledge points, rather than simply memorize and reproduce it (8). In addition, team-based learning helps promote deep learning and enhance problem-solving abilities, which are considered essential skills for health care professionals as they must retain knowledge and understand and incorporate new evidence as it becomes available (14). Our study specifically asked students to incorporate various evidence around the problem based on groups, which was a meaningful attempt of team-based learning.

In terms of materials, our props were completely independently designed based on authoritative theoretical bases, which could guide students’ thinking. With beautiful appearance and practicality, the props were concise and clear, highlighting the key points. Meanwhile, posters were low in cost and good environmentally. The results of the questionnaire showed that more than 80% of the students agreed the props were good learning aids. However, in the subjective question, some students complained that props were difficult to stick. We plan to further improve the material and use of the props, such as printing on hard cardboard and fixing with magnets, to make them easier to use and more suitable for learning.

In a word, we made adequate preparation before class. In class, we fully invited students to participate, so as to attract them to learn the intestinal absorption physiology through interesting tools. We are glad that our study has brought students real help for multiple aspects and expect more classes to be enlightened, creating better education.

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**DISCLOSURES**

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

**AUTHOR CONTRIBUTIONS**

Y.Y.C. and L.L.W. conceived and designed the research; L.Y.L, A.Z.H, X.N.L, Z.H.W., and Z.X.M. performed experiments; L.Y.L. and A.Z.H. prepared figures; L.Y.L. and A.Z.H. drafted manuscript; Y.Y.C. and L.L.W. edited and revised manuscript; Y.Y.C. and L.L.W. approved final version of manuscript.