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INSTRUCTIONAL DESIGN AND ASSESSMENT

A Board Game to Assist Pharmacy Students in Learning Metabolic Pathways

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Objectives. To develop and evaluate a board game designed to increase students' enjoyment of learning metabolic pathways; their familiarity with pathway reactions, intermediates, and regulation; and, their understanding of how pathways relate to one another and to selected biological conditions.
Design. The board game, entitled *Race to Glucose*, was created as a team activity for first-year pharmacy students in the biochemistry curriculum.
Assessment. A majority of respondents agreed that the game was helpful for learning regulation, intermediates, and interpathway relationships but not for learning reactions, formation of energetic molecules, or relationships, to biological conditions. There was a significant increase in students' scores on game-related examination questions (68.8% pretest vs. 81.3% posttest), but the improvement was no greater than that for examination questions not related to the game (12.5% vs. 10.9%).
Conclusion. First-year pharmacy students considered *Race to Glucose* to be an enjoyable and helpful tool for learning intermediates, regulation, and interpathway relationships.

Keywords: games, biochemistry, biochemical pathways, metabolic pathways, active learning

INTRODUCTION

The biochemistry of metabolic pathways is an important component of pharmacy education.[1] Biochemical pathways such as glycolysis, the tricarboxylic acid cycle, the electron transport chain, gluconeogenesis, triglyceride biosynthesis, and amino acid metabolism provide a basis for understanding the pathology of complex metabolic disorders, such as diabetes and cardiovascular disease. Students who are successful in biochemistry spend significant amounts of time studying the metabolic pathways, eg, by writing them out individually and as part of an interconnected network. However, many students find this process to be tedious and difficult, and thus fail to adequately learn and apply the material. A board game based on an integrated network of core biochemical pathways was developed in an attempt to increase students' learning enjoyment; familiarity with pathway reactions, intermediates, and regulation; and understanding of how individual pathways relate to one another and to selected physiological states.

Although the use of games in pharmacy education is widespread,[2-9] there are relatively few references in the literature to games that have been developed to enhance student learning of metabolic pathways.[10-13] Those that have been developed appear to be for general, undergraduate biochemistry courses and to emphasize the learning of intermediates and reactions, whereas features that may be more relevant to students in the health professions would include regulation of the pathways and their relationships to physiological events. The first report of a board game on metabolic pathways was for *Metabolism*, a game in which students "generate" adenosine triphosphate (ATP) by drawing cards that allow them to progress from one intermediate to another on a game board containing several interconnected metabolic pathways.[10] The object of the game is to acquire the most ATP. Although the game was "enthusiastically received," no data were provided about its effectiveness as a learning tool. In the game *Which Pathway Am I?*, a sheet of paper containing information about one of the metabolic pathways is attached to each student's back.[11] The students form pairs and then ask one another yes or no questions to determine the pathway with which they have been labeled. A 10-question pretest and posttest indicated that there was significant improvement in the students' ability to identify biochemical pathways as a result of playing the game. In *Metabolic War,* players compete to capture metabolic pathways one intermediate at a time, which students reportedly found helpful to their understanding of metabolic biochemistry.[12]Another reference was to an abstract for an online board game called *Metabola*, but this abstract did not reveal whether the game was evaluated with students nor did it describe how the

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game is played. Neither the online game nor its manual were available in English.[13]

This paper describes the implementation and assessment of *Race to Glucose*, a board game created to improve learning of the metabolic pathways by students in the first year of a doctor of pharmacy (PharmD) program.

DESIGN

Game Description and Rules

In *Race to Glucose*, players roll a die and move their game pieces along the gluconeogenesis pathway, starting at glutamate and ending at glucose. The first player to successfully move from the glutamate space to the glucose space wins the game. The names and structures of the intermediates and the names of enzymes are labeled along the pathway. Arrows are used to indicate the reaction direction, which is the same as the movement of the game pieces. The pathways included on the game board are glycolysis, gluconeogenesis, and the tricarboxylic acid (TCA) cycle (Figure 1). Truncated forms of other pathways also are included, and the game board could easily be expanded to include more (Figure 2).

Players must respond to quiz questions and to changes in physiological conditions as they proceed along the pathway. Spaces containing the structures of intermediates are alternately colored blue or purple, indicating the color of card a player should draw upon landing on the space. Purple cards are "quiz cards" and blue cards are "condition cards." Quiz cards, which are drawn by an opponent and read to the player who lands on the purple space, consist primarily of factual, free-response, or true/false questions about metabolic pathways. Example questions that were adapted from the game are listed in Appendix 1. With a correct answer, the player can roll and move on the next turn; if incorrect, the player must attempt to answer another quiz question on the next turn. Condition cards describe a metabolic state and direct the player to move in response to this state (eg, "Increase in insulin, move backward 3 spaces," or "Ethanol intoxication, go to 'lactate' space").

Players also start with 2 "regulator cards" and can draw another each time they land directly on an intermediate space. The regulator cards are printed with the names of enzyme regulators, such as "NADH (nicotinamide adenine dinucleotide hydride)" or "glucagon." A regulator card can be placed on the enzyme it regulates to "inhibit" or "activate" that enzyme. When a player lands on a space where a regulator has activated the enzyme, the number on the die is doubled. If it is a space where the enzyme has been inhibited, the player forfeits the turn. Regulator cards are returned to the deck after being used once.

Game Testing and Implementation

The game and an associated survey tool consisting of 12 multiple-choice and 3 free-response questions were pilot tested by faculty members and 12 volunteer pharmacy students prior to use. Modifications to both the game and the survey tool were made as a result of feedback from field testing. The game was played by groups ranging from 2 to 6 people. Play time varied based on the number of players and their ability to answer the quiz questions but was usually in the range of 30 to 60 minutes for a team of 5 to 6 players.

Following field testing, the game was prepared as a team activity for the 94 students of the pharmacy class of 2012 who were enrolled in the Metabolism of Carbohydrates, Lipids, and Amino Acids course at the Roseman University of Health Sciences, South Jordan, Utah, campus. This course is an academic block that consists of 84 classroom lecture hours and provides the equivalent of approximately 7 semester credits. The block content encompasses the metabolism of carbohydrates, lipids, and proteins and is team-taught at both campuses of Roseman University by 2 sets of instructors. Students were asked to play *Race to Glucose* as many times as possible within

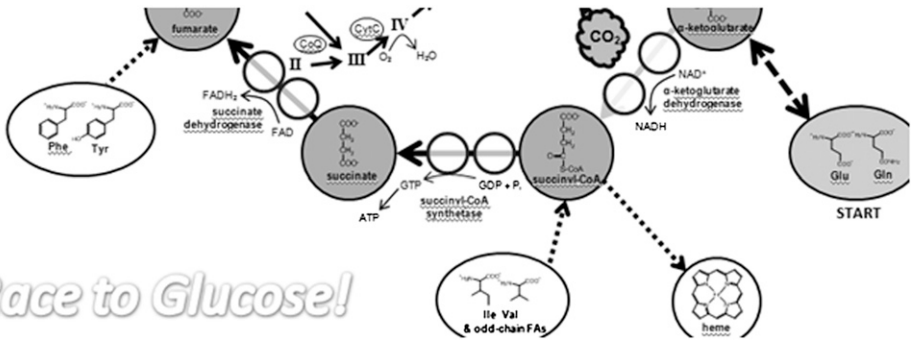

Figure 1. Portion of the game board for *Race to Glucose,* an educational game to teach pharmacy students about metabolic pathways. This excerpt shows the Start space, with nearby reaction arrows and intermediate spaces.

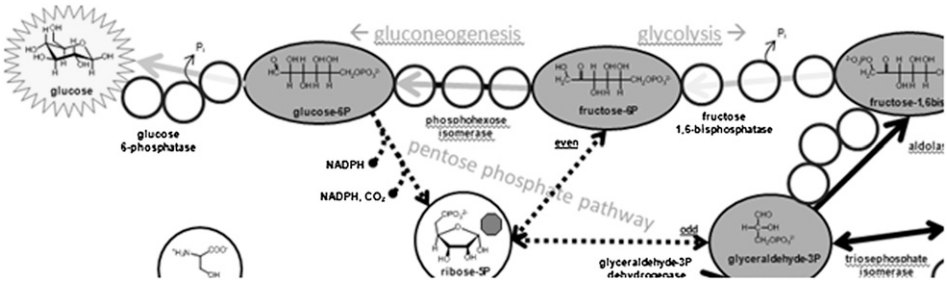

Figure 2. Portion of the game board for *Race to Glucose,* an educational game to teach pharmacy students about metabolic pathways. This excerpt shows the intermediate spaces and reaction arrows leading to glucose, the winning space.

roughly 2 hours allocated on 2 consecutive days of this course. Teams of 5 to 6 students were given a game board and all of the cards and pieces required to play. Each student was provided with an instruction sheet and a brief (<10 minute) in-class synopsis of the game. Students were encouraged to come up with their own "house rules" if they ran into problems and to concern themselves more with content than with adhering to a strict set of instructions. A pretest was given to the class on day 1, immediately prior to the introduction of the game. The game was played on days 1 and 2, then a posttest was administered on day 3.

EVALUATION AND ASSESSMENT

To encourage participation, completion of the pretest and posttest were anonymous. Students were instructed to enter their seat number or other unique identifying number on the pretest rather than their student identification number or name, and to use the same number on the posttest.

Each test contained 30 identical multiple-choice items. Thirteen of the 30 questions pertained to class material but were unrelated to game content. These were included to distinguish between learning attributable to game play versus learning acquired by any other means. The remaining 17 questions also addressed class material but were game-related. All 30 questions were based on learning outcomes from the 3 days of didactic instruction prior to administration of the pretest and were roughly proportional to the amount of class time devoted to each subject. The assignment of a question as "game-related" or "game-unrelated" was made based on the subject matter addressed in the question. Game-related questions dealt with glycolysis, the pyruvate dehydrogenase complex, the TCA cycle, the electron transport chain, the pentose phosphate pathway, and gluconeogenesis, all of which appeared on the game board, in the quiz questions, and/or in the condition cards. Questions unrelated to the game addressed topics that were taught by the same instructor but did not appear in game materials, including conversion of fructose and galactose to glucose, lactose and glucuronide synthesis, the polyol pathway, and bioenergetics.

Of 92 students in the class, 76 students completed the pretest and 68 completed the posttest. From this pool, 46 pairs of pre- and posttest survey instruments on which the same identifying numbers were used were identified and included in the analysis. A paired *t* test was used to compare the mean pretest and posttest scores for the 17 game-related questions and the 13 game-unrelated questions (Table 1). Significant improvements were observed in posttest performance on both the game-related (68.8% vs. 81.3%, $p < 0.001$) and game-unrelated (63.2% vs. 74.1%, $p < 0.001$) questions. Next, the mean improvement in performance on game-related questions was compared to the mean improvement in performance on game-unrelated questions using an unpaired *t* test (Table 1). A significantly greater mean improvement in posttest scores for game-related questions would suggest that the introduction of the game effectively enhanced student learning over standard methods of content delivery alone. No significant difference was found (12.5% increase on game-related vs. 10.9% increase on game-unrelated questions, $p = 0.13$). Student scores on game-related assessment

Table 1. Correct Responses on Pretest and Posttest for Pharmacy Students Who Played *Race To Glucose* (N = 46)

	Pretest Average Correct, No. (%)	Posttest Average Correct, No. (%)	Mean Improvement, No. (%)[b]
Game-related questions (out of 17)	11.7 (68.8%)	13.8 (81.3%)[a]	2.1 (12.5%)
Game-unrelated questions (out of 13)	8.2 (63.2%)	9.6 (74.1%)[a]	1.4 (10.9%)

[a] $p < 0.001$ for paired *t* test on posttest vs. pretest mean averages.
[b] $p = 0.13$ for unpaired *t* test on mean improvements in game-related vs. game-unrelated questions.

questions from the year in which the game was played also were compared to student scores on the game-related assessment questions delivered by the same instructor from 2 non-game years using a one-way ANOVA and the Tukey HSD post hoc test, but no significant differences were found (data not shown).

The effectiveness of the game as a learning tool was further assessed using an anonymous survey instrument administered on day 4 (after playing the game and completing the class assessment). Of 92 students, 47 returned the survey instrument, 46 of whom played the game. Student responses to the survey items are presented in Table 2. Approximately 45% of the students felt the game was introduced in the class at the right time, while 27.7% felt it was introduced too early, 12.8% felt it was introduced too late, and 6.4% were not sure. The majority of students (66%) played the game once or twice and 25.5% played the game 3 to 5 times. Students' written comments from the survey tool were compiled and summarized according to subject matter (Table 3). Common themes were that the quiz questions and regulator cards were helpful and that the game was enjoyable. Several of the students commented that the game helped them see the "big picture" of how the pathways interrelate. Comments about condition cards were split between those who found them helpful and those who did not. Most students who cited a least-beneficial aspect of the game commented on their own lack of preparation to play the game, but a few also commented about the amount of time it took to play the game, suggesting that time spent in individual study would be more effective. By far, the most common improvement suggested was to require the answering of more quiz questions during the course of the game.

DISCUSSION

The primary objectives for *Race to Glucose* were to help students increase (1) their learning enjoyment; (2) their familiarity with pathway reactions, intermediates, and regulation; and, (3) their understanding of how individual pathways relate to one another and to selected physiological states.

Based on the greatest number of survey respondents agreeing to the statement that *Race to Glucose* was fun, the first of these goals was met. In the free-response portion of the survey tool, students acknowledged that the game was enjoyable, a result supported by classroom observations. This result is also in line with similar observations in previous studies,[3,4,9,14] indicating that increasing student enthusiasm for learning the subject matter is a primary strength of incorporating games into a curriculum.

Regarding the second set of goals, more students agreed that the game was helpful in learning the regulation (61.7%) and intermediates (61.7%) of metabolism than in learning the reactions (48.9%), including which reactions produce energetic molecules (40.4%). The game allowed students to use regulator cards strategically during the game to speed their own progress or slow that of their opponents, thus helping to familiarize them with the regulators and their roles. The spaces of the game board and the condition cards would likewise be expected to highlight intermediates of metabolism. However, no specific effort

Table 2. Pharmacy Students' Perceptions About an Educational Board Game on Metabolic Pathways (N = 47)[a]

Race to Glucose . . .	**Agree, %**	**Neutral, %**	**Disagree, %**	**Not Sure, %**
Improved my understanding of how glucose metabolism is regulated.	61.7	27.7	8.5	2.1
Helped me learn the names of the chemical intermediates of glucose metabolism.	61.7	34.0	4.3	0
Helped me learn the chemical reactions of glucose metabolism.	48.9	36.2	12.8	0
Helped me learn which reactions of glucose metabolism are responsible for producing energetic molecules (eg, ATP, NADH)	40.4	44.7	8.5	2.1
Helped me learn how certain biological conditions (eg, hypoxia, ethanol consumption, exercise, etc) affect metabolism.	46.8	40.4	8.5	4.3
Helped me understand how multiple metabolic pathways (eg, TCA cycle, gluconeogenesis, glycolysis, pentose phosphate pathway, etc) work together in the liver.	70.2	21.3	8.5	0
Is a worthwhile team activity.	68.1	23.4	6.4	2.1
Helped me perform better on the assessment.	46.8	38.3	10.6	4.3
Self-study time is more useful to me than playing *Race to Glucose*.	42.6	42.6	14.9	0
Was fun.	83.0	14.9	2.1	0

Abbreviations: ATP = adenosine triphosphate; NADH = nicotinamide adenine dinucleotide hydride, TCA = tricarboxylic acid.

[a] Not all responses total 100% because some questions were left blank by respondents.

Table 3. Summary of Pharmacy Students' Comments Regarding the Educational Board Game *Race to Glucose* (N = 47)

What aspects of *Race to Glucose* were most beneficial to you?	
Quiz questions	21
Seeing the "big picture"/how the pathways are interrelated	16
Regulator cards or List of regulators	10
"Liked it"/Fun team activity	8
Condition cards	5
Other	3
What aspects of Race to Glucose were least beneficial to you?	
Did not study/was not prepared enough to make full use of the game	8
Condition cards	4
Time spent playing took away from/was not as effective as self-study	3
Regulator cards	3
Unhelpful for learning chemical reactions in the pathway	2
Not enough questions/stimulation of thinking	2
Other	3
What improvements would you suggest? Additional comments?	
More exposure to quiz questions/Add a rule that requires players to answer a quiz question before each move	10
Introduce later, before assessment, as a review	2
Introduce earlier, when students are not so stressed	2
Just give quiz questions/practice tests/review sheets instead of game	2
Other	7

was made to focus student attention on reactions beyond the regulated steps or on where energetic molecules are made.

The first of the third set of goals seems to have been met, as indicated by the high level of student agreement (70.2%) with the statement, "*Race to Glucose* helped me understand how multiple metabolic pathways work together in the liver." Seeing how the pathways interrelated also was frequently cited as a benefit of the game in the free-response portion of the survey instrument. This finding is attributed to the layout of the board and the tracing of the pathways required by game play. On the other hand, there was unexpectedly low agreement (46.8%) with the statement, "*Race to Glucose* helped me learn how certain biological conditions affect metabolism." There was also a split in the free-response section between those who thought the condition cards were most beneficial and those who thought they were least beneficial. The condition cards were meant to illustrate how metabolic pathways might respond to a number of selected physiological states by forcing players to move their game pieces in response to a condition (eg, insulin increase after a meal = move backward). However, a considerable number of respondents did not agree that this aspect of the game was helpful. Further study is warranted to determine the reasons for this response and ways to increase the efficacy of the condition cards.

While many respondents agreed that the game helped them learn about pathway intermediates and regulation and to see how individual pathways relate to each other, fewer (46.8%) believed that the game helped them perform better on the assessment. The improvements in posttest performance were significantly better for both game-related and game-unrelated questions, which was to be expected because both types of questions reflected class learning outcomes. However, there was not a significantly greater improvement in posttest scores for game-related questions, indicating that game use did not enhance student assessment performance over standard methods of learning. It is difficult to explain why the game was perceived to be a useful learning tool by students when it failed to significantly improve assessment scores. One possibility is that students significantly improved in correctly answering some game-related questions (ie, intermediates, regulation, and integration of pathways), but failed to do so on others (ie, reactions, energetic molecules, and the effects of biological conditions). More extensive pre- and post-testing consisting of a greater number of items clustered by subject area may provide additional insight.

One disadvantage of using educational games that has been previously observed is the increased amount of time required to learn by playing compared to other learning approaches.[15,16] An instruction sheet and brief synopsis of the game were provided to the class prior to play and there were few questions from the teams about game rules. However, this disadvantage still likely manifested itself in this study in 2 ways. First, while the survey respondents who agreed with the statement," Self-study was more useful than playing *Race to Glucose,*" did not comprise a majority (42.6%, Table 2), they did constitute a large minority. Comments in support of self-study were also made in the free-response section. Second, the teams were encouraged to play the game as many times as possible each day, but survey results indicate that the majority of students played the game only 1 or 2 times. Although game play appeared to be widespread on the first day, several teams devolved to only asking one another the quiz questions on the second day or not playing at all. When

asked about trend, students from these teams indicated that it was because they were stressed about the upcoming assessment and wanted to consume information as rapidly and efficiently as possible. Thus, the possibility of a decrease in learning efficiency as well as the student-acceptability of such a decrease should be considered by those who are contemplating implementing educational games in their classroom. To address this disadvantage, students suggested requiring a quiz question before each move to increase the delivery of information, challenge, and educational value of the game; however, this change might also result in an increase in playing time. Another similar variation would be to guarantee 1 move to each player on their turn, but to allow additional turns for each quiz question correctly answered. One student suggested that if a player was not able to answer a quiz question, other players should have an opportunity to answer the question and thus "steal" the turn. A rule of this kind would likely have the effect of increasing the pace of the game in addition to rewarding better-prepared players.

Another disadvantage associated with developing a board game of this type is the time required to prepare the materials. Once prepared, the materials can be reused from year to year, but a certain degree of commitment to – and enjoyment of – the creative process is required to make the project worthwhile. Instructors considering the use of games should be careful to choose a format to match the amount of time and energy they are willing to invest.

A noted strength of educational games is their ability to promote student-to-student interaction and peer learning.[15,16] *Race to Glucose* proved no exception, as evidenced both by in-class observations and student comments. The survey data also showed that a majority (68.1%) of respondents agreed that the game was a worthwhile team activity.

The data support the idea that *Race to Glucose* facilitated student learning in some but not all areas assessed in the metabolic pathways portion of the pharmacy curriculum. The game also appeared to promote team learning and improve student enjoyment of studying the pathways. Modifications to the game, such as increasing exposure to quiz questions and improving the efficacy of the condition cards, may enhance its usefulness as a learning tool. Further development of games and simulations that are effective in enhancing student enthusiasm for studying biochemistry as well as highlighting its relevance to the health professions would be a valuable contribution to those who teach in this field.

SUMMARY

A board game, *Race to Glucose*, was designed and implemented to increase pharmacy students' enjoyment of learning metabolic pathways. Most of the students surveyed agreed that the board game helped them learn certain aspects about the metabolic pathways related to the game (regulation, intermediates, and interpathway relationships) but not others (reactions, formation of energetic molecules, and relationships to biological conditions). The overall result was improved performance on game-related, assessment-like pretest and posttest questions, but not significantly greater improvement than for game-unrelated questions. In general, students enjoyed the game and thought it was a worthwhile team activity. Modifications to the game that further enhance its learning efficiency and relevance to physiology should be explored in the future.

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REFERENCES

1. AACP Educational Outcomes and Objective Supplement Development Task Force. Biology (biochemistry and molecular and cellular biology) supplemental educational outcomes based on CAPE 2004. http://www.aacp.org/resources/education/Pages/CAPEEducationalOutcomes.aspx. Accessed August 29, 2011.
2. Barclay SM, Jeffres MN, Bhakta R. Educational card games to teach pharmacotherapeutics in an advanced pharmacy practice experience. *Am J Pharm Educ*. 2011;75(2):Article 33.
3. Persky AM, Stegall-Zanation J, Dupuis RE. Students perceptions of the incorporation of games into classroom instruction for basic and clinical pharmacokinetics. *Am J Pharm Educ*. 2007;71(2): Article 21.
4. Roche VF, Alsharif NZ, Ogunbadeniyi AM. Reinforcing the relevance of chemistry to the practice of pharmacy through the Who wants to be a millionaire? learning game. *Am J Pharm Educ*. 2004; 68(5):Article 116.
5. Kennedy DH, Fanning KD, Thornton PL. The age game: an interactive tool to supplement course material in a geriatrics elective. *Am J Pharm Educ*. 2004;68(5):Article 115.
6. Evans S, Lombardo M, Belgeri M, et al. The geriatric medication game in pharmacy education. *Am J Pharm Educ*. 2005;69(3):Article 46.
7. Oliver CH, Hurd PD, Beavers M, et al. Experiential learning about the elderly: the geriatric medication game. *Am J Pharm Educ*. 1995;59(2):155-158.
8. Patel J. Using game format in small group classes for pharmacotherapeutics case studies. *Am J Pharm Educ*. 2008;72(1): Article 21.
9. Shah S, Lynch LMJ, Macias-Moriarity LZ. Crossword puzzles as a tool to enhance learning about anti-ulcer agents. *Am J Pharm Educ*. 2010;74(7):Article 117.
10. Goodman R. The game of "metabolism." *Am Biol Teach*. 1972; 34(2):75-78.

11. Ooi BG, Sanger MJ. "Which Pathway Am I?" Using a game approach to teach students about biochemical pathways. *J Chem Educ*. 2009;86(4):454-455.
12. Anjos CM, Gandra M. Metabolic war: a variation for metabolic biochemistry. *Revista Brasileira de Ensino de Bioquimica e Biologia Molecular*. 2008(Edicao Especial 8):Artigo 1.
13. Berkhout J. A board game reinvented-an online game on metabolism of cells as an open educational resource. Online Educa, 2008; Berlin, Germany. http://dspace.ou.nl/handle/1820/1661 Accessed October 17, 2011.
14. Cessario L. Utilization of board gaming for conceptual models of nursing. *J Nurs Educ*. 1987;26(4):167-169.
15. LeCroy C. Games as an innovative teaching strategy for overactive bladder and BPH. *Urol Nurs*. 2006;26(5):381-384.
16. Walljasper D. Games with goals. *Nurs Educ*. 1982;7(1): 15-18.

Appendix 1. Examples of Quiz Card Questions and Answers Adapted from Race to Glucose

Q. True or False: The pentose phosphate pathway occurs in the cytoplasm. A. True. The PPP branches from glycolysis, which also occurs in the cytoplasm.
Q. How does ethanol metabolism promote anaerobic glycolysis in humans? A. NADH is produced during ethanol metabolism, which promotes conversion of pyruvate to lactate.
Q. What effect would an uncoupler of oxidative phosphorylation have on cellular oxygen consumption? A. It would increase cellular oxygen consumption.
Q. How many acetyl-CoA molecules can be biosynthesized from one glucose molecule in glycolysis? A. 2 acetyl-CoA molecules.
Q. What molecule is an intermediate for gluconeogenesis but NOT an intermediate for glycolysis? A. oxaloacetate.
Q. What effect would an increase in NADH have on the TCA cycle? A. It would inhibit the TCA cycle.

Abbreviations: Q = question; A = answer; PPP = pentose phosphate pathway; NADH = nicotinamide adenine dinucleotide hydride; acetyl-CoA = acetyl coenzyme A; TCA = tricarboxylic acid.