

Team-Based Learning in: "MICROBIAL PHYSIOLOGY"

1. Course Situation

- Department: Botany-Microbiology
- Subject: Microbial Physiology
- Level: Upper Division
- Students: N = 55-70; most are senior-level microbiology majors
- Time Structure: 3 class sessions per week, 50 min. each; 16 weeks.
- Any special course or classroom factors: none

2. Learning Goals for the Course

- Knowledge of metabolic pathways in diverse microorganisms
- Understand mechanisms of energy production, carbon-carbon bond cleavage, and cofactor function
- Ability to apply metabolic principles in new contexts
- Ability to hypothesize new pathways, based on data about organisms

3. Reasons for Changing to Team-Based Learning

- Previous way of teaching: primarily lecturing
- Problems encountered:
 - Students were overwhelmed with the number of pathways
 - Retention of knowledge was poor
 - Knowledge of pathways learned earlier could not be applied later in course

4. Changes Made

- Initial changes (Fall 2000): Introduced RATs (Readiness Assurance Tests) only
- Result?
 - Class was more energetic
 - But retention of knowledge did not improve (as indicated by final exam performance)
- Later changes (Fall 2001, 2002): Added group projects: 2 per semester
 - Results: Retention of knowledge and ability to apply greatly improved

5. Examples of Team Assignments

- Mid-semester: Identify the pathway for the metabolism of a compound and amount of ATP made, based on an extensive dataset

- Specific example: Take data from one organism and apply that data to the metabolism of *trans*-aconitate by a rumen bacterium. The students had to determine whether new data were consistent with known pathways for *trans*-aconitate metabolism based on their readings. If not, the students had to propose a pathway or a modification of an existing pathway to explain the data (see appendix for example of data set).
- End-of-semester: Focused on problems related to chemiosmotic mechanisms of energy conservation.
 - Specific example: Take textbook's explanation of electron transport chain of sulfate-reducing bacteria. Question: Should it be modified in light of recent papers describing properties of mutants defective in one or more of the components of electron transport chain. If so, propose an electron transport chain that is consistent with the properties of the mutants and generates a sufficient number of protons on the outside of the cell to explain previously published molar growth yields (see appendix for example).

6. Impact of Team Assignments

A. On Student Learning and Performance:

- Retention of knowledge as shown on final exam: up significantly.
 - Mean score on final exam: increased from 133 (2000) – 150 (2001) – 158 (2002) [Max: 200]
- The proportion of the students with grades of 90-100% was more or less the same (up slightly but not dramatically). But the percentage of students with grades below 70% decreased significantly and the percentage with 70-90% increased significantly.
 - The first piece of data suggests that the difficulty of the exam was comparable to previous years. The second piece of data suggests that this form of teaching helped the majority of students to improve their overall understanding of the subject.
- Groups were able to solve very challenging research problems.

B. Student Attitudes

- Student ratings of the course rose significantly
- 80% made favorable comments about the course and the teacher
- Students thought that they learned more and developed critical thinking skills (statistically significant improvement), using this form of learning.

7. On the Teacher

- Enjoyed a new and different kind of class dynamics: students were more learning-centered and less grade-centered. Impact: students were

anxious to talk about the complexities of microbial physiology outside of class with the teacher, and not just about their scores on recent exams.

- Improved student evaluations: the class and instructor were rated in the top 10 percentile of all courses taught in the college.

8. Related Publications

- Prof. McInerney has published an essay on this teaching experience in *Microbiology Education*, Vol. 4 (May, 2003) a periodical sponsored by the American Society for Microbiology.

9. Contact Information

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10. APPENDIX: More Detailed Material about Team Assignments and Products

- **Examples of two assignments are provided below: one given a mid-semester and one at the end of the semester.**
- **Also, at the end of this appendix are samples of what two teams produced in response to these problems.**

Example 1. Mid-Semester Project on the elucidation of a metabolic pathway.

MBIO 4853, Individual and Group Project 1
Spring, 2002

Points: 10 points each for individual and group portion of this project

Due dates: Wednesday, March 13, 2002. One-page individual write up due.
Friday, March 15, 2002. Group poster due for review by class.

Introduction:

Grass tetany is a potentially fatal disease in cattle and is characterized by symptoms of hypomagnesemia. The cause of the hypomagnesemia is perplexing, but is related to feeding cattle grass with high levels of *trans*-aconitic acid. Some research indicates that *trans*-aconitic acid is reduced to tricarballic acid by rumen bacteria (see figure below). Tricarballic acid is a potent magnesium chelator, is slowly degraded in the rumen, and is freely diffusible into the blood stream of the cow. For these reasons,

it is believed that the generation of tricarballic acid in the rumen is the cause of grass tetany. Strain AO is a rumen bacterium that oxidizes *trans*-aconitic acid. This strain is a strain of *Acidaminococcus fermentans* (Cook et al., 1994). The addition of strain AO to rumen contents or to a cow decreased the conversion of *trans*-aconitic acid to tricarballic acid. Supplementing the diet with cells of strain AO may be an effective method to prevent grass tetany.

The metabolism of *trans*-aconitic acid by strain AO is controversial. Cook and Russell (1994) hypothesized that *trans*-aconitic acid and glutamate are degraded by the 2-oxoglutarate pathway. However, additional data on the metabolism of glutamate and *trans*-aconitic acid by strain AO are now available and this conclusion needs to be reconsidered. These new data are given below.

First, read the papers on the blackboard web site that discuss the metabolism of strain AO and how to elucidate pathways using position-labeled substrates and detection of key enzyme activities and intermediates. Use this background information to interpret the data given below. The object is to postulate a pathway for *trans*-aconitic acid metabolism that is consistent with the fermentation products, molar growth yield, and enzyme, intermediate and labeling data. The pathway could be one that is already known, a variation of a known pathway, or a new pathway. It is up to you to decide.

Schedule:

Wednesday, March 13, 2000. A one-page write up and a diagram of the pathway (on a second sheet of paper if necessary) are due from each individual. You should a) present your hypothesis for *trans*-aconitic acid metabolism (e.g., the figure or diagram), b), discuss how your pathway is consistent with the data, and c) discuss whether the experimental data is or is not consistent with known pathways for glutamate metabolism. You will also be given time to discuss your ideas with your group.

Friday, March 15, 2002. Each group will be given several sheets of paper on which to write your consensus pathway and any explanation associated with it. You should clearly indicate the fate of each carbon of *trans*-aconitic acid in your pathway and present sufficient information so that I and the other groups will be able to determine whether your pathway is consistent with the data. Do not place any identifying marks on your poster yet. You will hang your poster on the wall for review by myself and the other groups. Each group will determine if the posters from the other groups have a high, medium or low probability of explaining the experimental data. On my command, each group will simultaneously post their assessment of each poster except their own. This will be done by using color-coded, post-it notes. Each note will have your group number on it. We will then discuss the posters and allow the groups to defend or further explain their reasoning.

Remember, I will assess each poster and your assessment of each poster. If I feel that the assessment was not done seriously, I will deduct points from your group grade. Thus, if you rate a bad poster as an excellent one (or visa versa), I will deduct

points from your group grade for each incorrect assessment. This is not Olympic Figure Skating so collusion is not allowed.

Required Readings: (available as JPEG files on blackboard web site).

The first two papers discuss how a pathway for metabolism can be elucidated.

A. J. M. Stams, C. Dijkema, C. M. Plugge, and P. Lens. 1998. Contribution of ^{13}C -NMR spectroscopy to the elucidation of pathways of propionate formation and degradation in methanogenic environments. *Biodegradation* 9: 463-473.

C. M. Plugge, J. M. van Leeuwen, T. Hummelen, M. Balk, and A. J. M. Stams. 2001. Elucidation of pathways of catabolic glutamate conversion in three thermophilic anaerobic bacteria. *Arch. Microbiol.* 176: 29-36.

The last paper specifically addresses *trans*-aconitic acid metabolism in *Acidaminococcus fermentans*.

G. M. Cook and J. B. Russell. 1994. Dual mechanisms of tricarboxylate transport and catabolism by *Acidaminococcus fermentans*. *Appl. Environ. Microbiol.* 60: 2538-2544.

New Experimental data:

1. Products produced from *trans*-aconitate:



2. Molar Growth yield:

~ 8 g (dry weight) per mole of *trans*-aconitic acid.

3. Metabolism of position-labeled substrates: As indicated below, radioactively labeled substrates were added to washed cells of strain AO grown with the same compound as the energy source.

No incorporation of radioactivity was detected in acetate or butyrate when [5- ^{14}C]-glutamate was used.

When [5- ^{14}C]-*trans*-aconitate was used, radioactivity was detected in carboxyl group of acetate. The specific activity of acetate (disintegrations per mmol) was one-half of the specific activity of [5- ^{14}C]-*trans*-aconitate.

Table 1 Enzyme activities detected in cell-free extracts of strain AO. Enzyme activities are expressed as μmol per min per mg of protein.

Enzyme activity	Glutamate-grown cells	<i>trans</i> -aconitate-grown cells
Citrate lyase	0.3	0.4

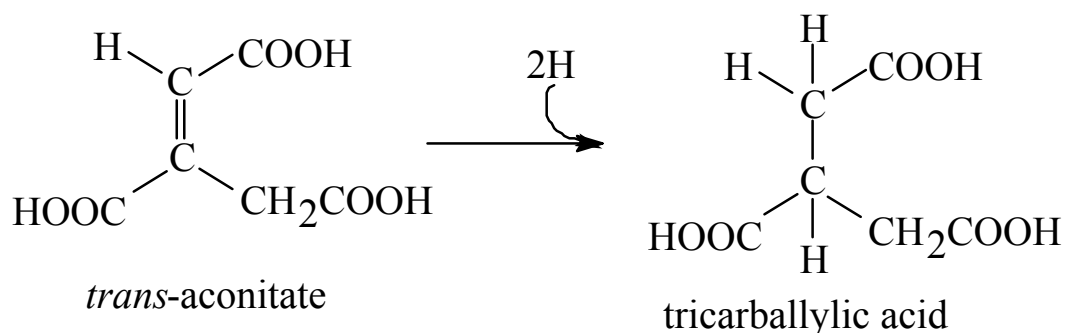
Oxaloacetate decarboxylase	0.5	0.5
Pyruvate:ferredoxin oxidoreductase	ND*	0.1
Hydrogenase	0.3	0.8
Glutamate dehydrogenase	34	20
Glutaconate CoA transferase	2.0	2.2
Glutaconyl-CoA decarboxylase	3.0	0.2

Table 2. Intermediates detected during the metabolism of 25 mM glutamate or *trans*-aconitic acid by cell-free extracts of strain AO. All concentrations are in mM. Note: the extracts were treated with acid prior to analysis. This would have removed CoA from any of the intermediates.

Compound detected	<i>trans</i> -aconitate	Glutamate
Citrate	8.5	ND*
<i>cis</i> -aconitate	0.9	ND*
Oxaloacetate	1.6	ND*
Pyruvate	0.5	ND*
2-oxoglutarate	ND*	0.7
Glutaconate	ND*	0.55

* ND means not detected.

Reduction of *trans*-aconitic acid.



Example 2: End of Semester Project on Electron Transport and Chemiosmosis.

MBIO 4853, Individual and Group Project 2

Spring, 2002

Points: 10 points each for individual and group portion of this project

Due dates: Wednesday, April 17, 2002. One-page individual write up due.

Friday, April 19, 2002. Group poster due for review by class.

Model for the electron transport system in *Desulfovibrio* species.

Introduction:

Sulfate-reducing bacteria perform anaerobic respiration, which leads to the synthesis of ATP. The exact mechanism for the generation of the proton motive force is still under investigation. I have given you 3 papers that discuss the bioenergetics systems of *Desulfovibrio* species when they grow with sulfate as the electron acceptor and either lactate, pyruvate or hydrogen as the electron donor. The mini-review provides a concise summary of the electron carriers detected in sulfate reducers. Recently, two new papers have been published that describe the effects of mutations of cytochrome c_3 and Fe-only hydrogenase on the growth of sulfate reducers. In light of these new publications, do we need to revise the model for hydrogen production and use as described in the Voordouw review and in your textbook? In addition to the redox components discussed in the minireview by Prof. Voordouw, sulfate-reducing bacteria are also known to contain menaquinones and cytochrome b_6 .

Project Goal:

Your goal will be to provide a model for electron transport, sulfate reduction and hydrogen metabolism in *Desulfovibrio vulgaris* that is consistent with the properties of the mutants and the molar growth yields of the organism with pyruvate and lactate as electron donors and sulfate as the electron acceptor. Read the three papers that are available on the blackboard web site. Use this information, the discussion of sulfate reducers in your book and the molar growth yields given below to formulate your model.

Published Data (Magee et al., 1978, Arch. Microbiol. 117: 21-26):

Molar growth yields: The molar growth yield of *Desulfovibrio vulgaris* is 9.7 gram dry weight per mole of pyruvate. With lactate as the electron donor, the molar growth yields are 6.0 gram dry weight per mole of lactate and 12.4 g. dry weight per mole of sulfate. Remember that two lactates are required to reduce one sulfate.

Schedule:

Wednesday, April 17, 2002. A one-page write up and a diagram of the electron transport (on a second sheet of paper if necessary) are due from each individual. Your write up should provide a concise explanation in support of your hypothesis (model) of the electron transport system. This will constitute your individual grade. You will also be given time to discuss your ideas with your group.

Friday, April 19, 2002. Group presentation. Each group will be given several sheets of paper on which to write your consensus electron transport system and any explanatory information you think is needed. You should have sufficient information so that I and others in the class can understand your reasoning. **Do not place your group number**

on the poster at this time. You will hang your poster on the wall for review by myself and the other groups. Each group will determine if the posters from the other groups have a high, medium or low probability of explaining the experimental data. On my command, each group will simultaneously post their assessment of each poster except their own. This will be done by using color-coded, post-it notes. Each note will have your group number on it. We will then discuss the posters and allow the groups to defend or further explain their reasoning.

Remember, I will assess each poster and your assessment of each poster. If I feel that the assessment was not done seriously, I will deduct points from your group grade. Thus, if you rate a bad poster as an excellent one (or visa versa), I will deduct points from your group grade for each incorrect assessment. This is not Olympic Figure Skating so collusion is not allowed.

Required Readings: (available as pdf files on the blackboard site).

1. G. Voordouw. 1995. The genus *Desulfovibrio*. Appl. Environ. Microbiol. 61: 2813-2819.

Mini review that discusses what was known at the time about the role of various electron carriers and membrane proteins in sulfate reduction and hydrogen metabolism.

Papers on properties of mutants:

2. B. J. Rapp-Giles, L. Casalot, R. S. English, J. A. Ringbauer, A. Dolla, and J. D. Wall. 2000. Cytochrome c_3 mutants of *Desulfovibrio desulfuricans*. Appl. Environ. Microbiol. 66: 671-677.

Discusses how a mutation in cytochrome c_3 affects growth on lactate, pyruvate and hydrogen.

3. B. K. J. Pohorelic, J. K. Voordouw, E. Lojou, A. Dolla, J. Harder, and G. Voordouw. 2002. Effects of deletion of genes encoding Fe-only hydrogenase of *Desulfovibrio vulgaris* Hildenborough on hydrogen and lactate metabolism. J. Bacteriol. 184: 679-686. Discusses the effect of deleting the periplasmic hydrogenase on hydrogen and lactate growth.

Figure 1. One team's response to the **mid-semester project** on elucidation of a pathway for trans-aconitate metabolism.

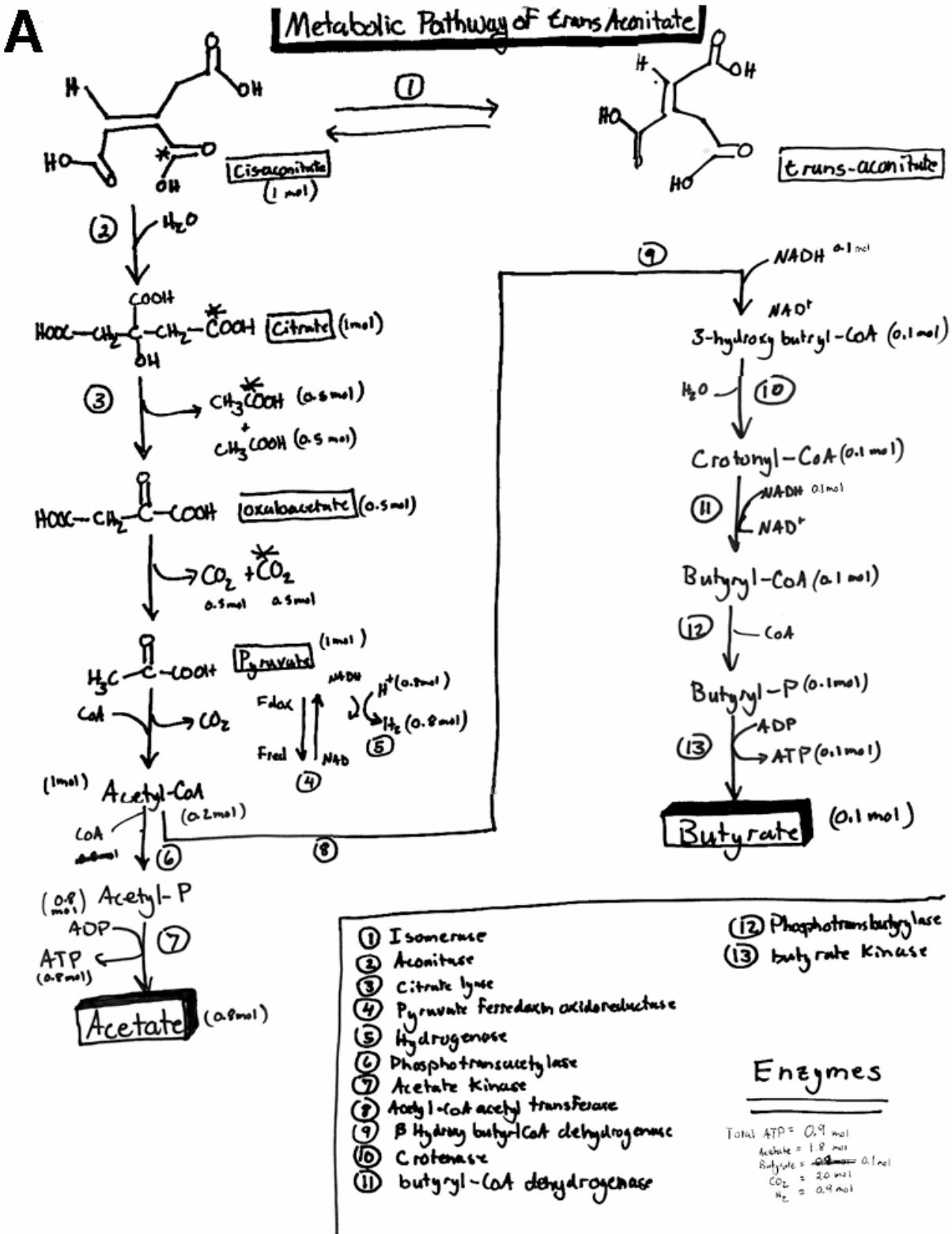


Figure 2. Example of one team's response to the **end of semester project** on electron transport chain of sulfate-reducing bacteria.

