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The original biotechnology: brewing an undergraduate education

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The increasing number of microbreweries and brewpubs and the popularity of homebrewing present a heady opportunity for undergraduate projects that blend together theory, practice and job opportunities in the realm of fermentation science. However, a perception of prohibitive regulation on campus and other concerns has led many instructors to abandon that most practical demonstration of fermentation, the production of ethanol by *Saccharomyces cerevisiae*. We present our success in introducing fermentation using homebrewing in a microbiology laboratory. Virtually all fundamental topics of microbiology are remarkably easy to demonstrate with this project: growth and replication, physiology, limitation of growth by sterilization and other methods, competition, energy conservation and utilization, consequences and uses of mutations, and genetic engineering are among the topics which dovetail with this activity. Further, this activity also represents a natural introduction to a number of industrial topics: issues of scaling-up, pilot tests and environmental conditions. *Journal of Industrial Microbiology & Biotechnology* (2000) **24,** 327–333.

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Introduction

Systematic fermentation of fruit and grain are defining characteristics of civilization, correlating with the change from nomadic to agrarian society [30]. Pasteur's work in the 1860s with the French wine industry was similarly a seminal event in the origins of formal microbiology [18]. However, presentations of alcohol production are limited in scope, or completely absent, in the current curricula of most undergraduate biology and chemistry programs. When included in lecture, 'alcoholic fermentation' is one of six categories of fermentation end products [6]. When commercial production of alcohol is mentioned, it is presented as an example of industrial microbiology, with large-scale commercial producers (eg, gasohol) as the prototype [6]. Where it is included in the laboratory experience, fermentation of plant extracts is performed as a demonstration, rarely with any variables, with aural (but never oral) evaluation of ultra small-scale (5–100 ml) production. In a survey of ten widely distributed manuals, only three included protocols for the fermentation of small volumes of grape juice [1,9,12]. One manual included a protocol for brewing; however, a lack of detail makes it inadequate for student or faculty use [7].

During her first 5 years as the department microbiologist, Waechter-Brulla had students produce wine using small batch methods with unsavory results. In this activity (similar to an exercise in Ref [12]), 100 ml of grape juice were transferred into a Pyrex bottle which had a 10×100-mm test tube taped to its side. An inverted U-shaped glass tube, passed through a rubber stopper, acted as a gas outlet from the bottle to the water-filled test tube. Following inoculation with yeast and 1–2 weeks incubation, students observed a simple demonstration of fermentation and manufactured a repulsive fluid to pour down the drain. Although the exercise provided a demonstration of fermentation, it revealed little else and conveyed little practical information. This is unfortunate—with relatively little extra time, effort and money, students could receive special insight and an introduction to a multibillion-dollar industry with jobs, money and growth as well as botanical, microbial, and economic importance [8,10,20].

Along with the recent increase in microbreweries and brewpubs throughout the country, there is a growing interest among students in making beer or wine at home. The building of a local microbrewery and the arrival of Woller, an animal physiologist with a decade of homebrewing experience, delivered a way to exploit this interest. We developed this laboratory for our department's introductory microbiology course, in which students produce a batch of beer in the laboratory setting, using the tools and steps appropriate for homebrewing. Extensive detail encourages even the novice to participate.

The popularity among students, and notoriety on campus, of this laboratory project provide an opportunity to discuss responsible consumption of alcoholic beverages and evaluate one's choices and goals in life [19,31]. We expect students to consume the product if they are legally able to do so and if they choose to do so. By having students perform this exercise with the expectation that they will produce a potable product, the activity gains legitimacy in their eyes.

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Further, it acts as a demonstration of a number of themes and concepts for an introductory microbiology course—what you are doing does tie into theory, and what you are learning *is* applicable to life. The activity also enlightens the rest of our general biology department to some of the opportunities available to our majors in commercial settings. Fundamental issues in industry can be incorporated in discussions; these include equipment design, economics of production, kinetics, scale-up, regulation and safety [8,10,14,15,20].

The broadened presentation of brewing also ties into current topics, such as the impact of European Common Market demands on the German tradition of purity in brewing [33]. Current findings in archaeological research on the origins of civilization [29,34] provide a chance to talk about food preservation, changing social mores, and migration. A number of student projects have developed from this exercise, some of them done in conjunction with a local restaurateur. Reports requiring library and web-based information provide reinforcement of search skills and an appreciation of the economic impact, and job market potential, of the fermented beverage and food industry.

Materials and methods

Organisms

Brewing-yeast strains were purchased from commercial suppliers. The strain chosen was based on the type of beer being produced (*Saccharomyces cerevisiae*, a top-fermenter, for ales or *S. uvarum* (also called *S. carlsbergensis*), a bottom-fermenter, for lagers).

Media

We used commercially available kits or individual components purchased separately from homebrewing suppliers. Essential components included malt (malt extract, malt powder, or malted whole grain) and hops (bittering and aromatic). Amendments included brewing salts (gypsum, non-iodized sodium chloride), clarifying aids (Irish Moss), or corn sugar, based on the requirements of the batch. Other accessory ingredients included honey, berries, or assorted fruits. These consumable supplies are listed in Tables 1, 2, and 3 according to the activity for which they are needed (primary fermentation, secondary fermentation and bottling, respectively). In these three tables we have integrated media, equipment and protocols for the 3 days of lab work. Although detailed, the tables are ready for direct use.

Equipment

Homebrewing and other kitchen equipment were purchased as individual pieces; alternatively they can be purchased in 'starter kit' form from any homebrewing supplier. The specific equipment needs for each activity are listed in Tables 1, 2, or 3, according to the activity for which they are needed.

Primary fermentation

The protocol for establishing the primary fermentation is given in Table 1. After students thoroughly clean the area and equipment, water for the wort and for sanitization of equipment is brought to a boil. Malt is added to one batch

Table 1 Session 1—primary fermentation

Materials

Equipment:	Consumable supplies:
Burners, strikers, tripods Pots [at least three; 8–12 L (8–12 quart) capacity] Thermometer Graduated cylinder (100 ml) Hydrometer Spoons and ladle Lauter tun (if whole grain) Can opener (if canned malt extract) Tubing (2 m length, 7 mm id[a]) Tongs (two pair) Fermenter Fermenter lock Rubber stopper	– sanitizer (one 1 liter/1 quart container will cover all sessions) – water – chlorine bleach (one 1 liter/1 quart container will cover all sessions) – homebrewing kit (one), or – components: (amounts will depend on recipe) malted barley hops yeast – amendments: (amounts will depend on recipe) NaCl gypsum Irish moss – other amendments (per recipe): yeast starter

Procedures

Cleaning regimen:

1. Clear work surfaces of unnecessary materials.
2. Wash off work surfaces with sanitizer and sponges.
3. Mop floor with sanitizer.
4. Set out equipment and supplies.
5. Inspect all equipment for residual contamination. Rinse with bleach then with water.
6. Boil 3 L tap water to be used for sanitizing utensils.
7. Boil 6 L tap water to be used for sparging grains if using whole grains.

Establishment of primary fermentation:

1. Boil 4 L tap water to be used for wort.
2. Transfer malt to water.
   a) If using kit: warm can of extract, then open and pour contents into water.
   b) If using whole grains: weigh out desired quantity, crush or grind (to crack shells and increase surface area), pour into water, stir for 1 h, then collect fluid. Perform hot aqueous extraction (sparging) of grains, and add this to fluid in primary vessel. This comprises the 'wort'.
   c) If grains need to be inverted, allow an extra 40–80 min.
3. Add bittering hops.
4. Adjust heat, maintain at low boil (100°C) for 45–60 min.
5. Sanitize primary fermentation vessel with bleach. Rinse with four volumes of water.
6. Put 16 L tap water into primary fermentation vessel.
7. Approximately 5 min prior to end of heating, add a second aliquot of hops (aromatic).
8. Pour wort from pot into water in primary fermentation vessel.
9. Monitor temperature; when below 25°C, add yeast.[b]
10. Close vessel (lid or rubber stopper), and add sterilized fermentation lock.
11. Transfer vessel to relatively cool (15–25°C), dark, secluded site.[c]

[a]id = inner diameter.
[b]We use pre-sterilized, pre-frozen ice blocks to chill the wort. This drops the temperature in ~10 min, rather than 30–90 min using ice baths; it is an excellent demonstration of thermodynamics and surface area.
[c]A cupboard under a side bench is ideal, especially when handles can be secured with a bicycle lock.

Table 2 Session 2—secondary fermentation

Materials	
Equipment:	Consumable supplies:
Burners, strikers, tripods Pot (6 L capacity) Tubing (2 m; 7 mm id) Tongs (two pairs) Graduated cylinder Hydrometer Fermenter Fermenter lock (re-use lock from Session 1) Rubber stopper	– sanitizer (see Table 1) – water – chlorine bleach (see Table 1) – corn sugar or dry malt extract (amount will depend on recipe)

Procedures

Monitor progress:

1. Check each day for fermentation (carbon dioxide production).
2. When fermentation appears to be slowing (day 4 or 5), test sugar utilization daily using hydrometer to determine SG.
3. Evaluate the amount of yeast cell sedimentation in the bottom of the fermentation vessel daily.
4. When rapid fermentation has ceased (~7 days), transfer wort from primary into secondary fermentation vessel (below).

Cleaning regimen:

1. Clear work surfaces of unnecessary materials.
2. Wash off work surfaces with sanitizer and sponges.
3. Mop floor with sanitizer.
4. Set out equipment and supplies.
5. Inspect all equipment for residual contamination. Rinse with bleach then with water.
6. Boil 6 L tap water to be used for sanitizing utensils and hose for siphon.

Transfer to secondary fermenter:

1. Sanitize appropriate equipment: secondary vessel, hose, and fermentation lock.
2. Place primary vessel on bench top; place secondary vessel on floor immediately below.
3. Use boiled water in hose to establish siphon. (Transfer via siphon limits oxidation of the wort, crucial to quality of final product.)
4. Continue transfer until all but final few mm above yeast cell sediment has been transferred.
5. Close vessel (lid or stopper), add fermentation lock to new vessel.
6. Transfer new vessel to incubation area.

of water to form the wort. The length of time for maintenance of high temperature varies by batch. We recommend that instructors follow recipe recommendations of time for inversion of whole grains and cooking of wort. The term inversion, as used by homebrewing enthusiasts, refers to the conversion of sugars in the plant extract to forms fermentable by the yeast; it includes changes in optical properties, as first described by 19th century biochemists. These extended incubations, requiring the attention of only one or two students to stir and monitor temperature, provide a natural moment for presentation of background topics. Once complete, the wort is transferred to the primary fermentation vessel. To limit contamination and oxidation, we transfer via siphon. Previously boiled and cooled or frozen

Table 3 Session 3—bottling

Materials	
Equipment:	Consumable supplies:
Burners, strikers, tripods Pots (three; 8–12 L capacity) Tubing (2m length, 7 mm id[a]) Tongs (two pair) Graduated cylinder (100 ml) Hydrometer Bottling tube (spring-activated release) Bottles (between 50 and 60) Bottle brush Bottle washer Bottle capping device	– sanitizer (see Table 1) – water – chlorine bleach (see Table 1) – corn sugar or dry malt extract—approx 250 g (1 cup), but will depend on hydrometer reading – bottle caps (available in bags of 144)

Procedures

Monitor progress:

1. Test sugar utilization, using hydrometer to determine SG.
2. Evaluate yeast cell sedimentation in the bottom of the fermentation vessel.
3. When fermentable sugars have been consumed (SG remains the same on three consecutive days), prepare to transfer wort from secondary fermenter to bottles (below).
4. Upon purchasing bottles, run through equipment washer prior to storage.

Cleaning regimen:

1. Clear work surfaces of unnecessary materials.
2. Wash off work surfaces with sanitizer and sponges.
3. Mop floor with sanitizer.
4. Set out equipment and supplies.
5. Inspect all equipment for residual contamination, especially the bottles.
6. Boil 3 L tap water to be used for sanitizing utensils and bottlecaps.
7. Boil 6 L tap water to be used for sanitizing hose for siphon.
8. Boil 1/2 L tap water to be used for dissolving sugar (~375 g per 5 gallons wort) or dry malt (~625 g per 5 gallons wort) for in-bottle carbonation.

Bottling:

1. Clean bottles by submerging them in cold water with bleach.
2. Rinse with 4–5 changes of water, or until chlorine cannot be detected.
3. Test SG of wort.
4. Transfer wort to clean sterile vessel by siphon.
5. Calculate weight of corn sugar or dry malt extract to add to provide carbonation.
6. Dissolve sugar in boiling water, cool, then add to bulk wort.
7. Transfer vessel with wort to bench top and bottles to floor below.
8. Place bottling tube at one end of hose.
9. Establish siphon and begin transfer.
10. Continue filling bottles until wort is gone.
11. As bottles are filled, transfer them to bench top.
12. Place boiled bottle cap on bottle and secure with bottle capping device.
13. Transfer bottles into case or other box for transportation.
14 Transfer cases to secure location for aging at 15–20°C/55–65°F.

water is added to achieve the appropriate final volume and temperature. According to batch requirements, the wort is inoculated with yeast in the appropriate form (strain; liquid culture or dried and dissolved; amount; addition or not of yeast starter). The vessel is closed, a fermentation lock is added, and the vessel is incubated at a suitable temperature in a dark enclosure. Chemicals in the wort and in the mature beer are sensitive to photochemical reactions, leading to 'skunky' (or in Britain, 'catty') beer. Total time for this day's session varies from 2 to 5 h, depending primarily on whether a kit (shorter time) or whole grains (longer times) are used for the malt source.

Monitoring progress

Progress of fermentation is first monitored each day by examination for production of carbon dioxide bubbling through the fermentation lock. Once bubbling ceases, small aliquots (100 ml, or $\frac{1}{2}$ cup) are removed from the top of the batch using a sterile pipet and transferred to a 100-ml graduated cylinder. A hydrometer is floated in this container to determine specific gravity (SG). Fermentation is allowed to continue until reaching the pre-determined endpoint or until no change in sugar content is evident for 3 days.

Secondary fermentation

Once primary fermentation is complete (~7–10 days), the wort is transferred from the primary fermentation vessel to the secondary fermenter; details are given in Table 2. After thorough cleaning of the area and equipment, a sanitized siphon is used to transfer the supernatant from the primary fermenter to a second vessel. The sediment, primarily dead yeast cells, is left in the primary fermenter and subsequently discarded. Sufficient viable yeast remain in suspension to complete the secondary fermentation. Following transfer, the secondary fermenter is closed, and a freshly-cleaned and sanitized fermentation lock is added. The vessel is then placed back in the incubation area.

Bottling

Once the secondary fermentation is complete (~2–3 weeks), the beer is transferred to rigorously sanitized bottles, as described in Table 3. After thorough cleaning of the area and equipment, boiling water is used to sanitize the tubing and the bottle caps. Depending on batch requirements, an additional aliquot of sugar or malt extract may be dissolved in boiling water and then added to the bulk batch; this energy source will support in-bottle carbonation. The amount will be roughly 250 g (1 cup); however it must be calculated based on the specific gravity as determined with the hydrometer; the provision of significant excess energy will lead to over-carbonation and possible explosions. A sterile bottling tube with spring-activated release is attached to one end of the tubing, and a siphon is established. The contents of the first bottle, which includes water in the tubing, is discarded. As each bottle is filled, a bottle cap is placed on top and crimped securely. Bottles are cased and transported to a secure location for aging, to avoid contamination and unauthorized consumption. A residential basement provides the cool temperature, darkness and limited access needed for this stage.

Legal issues

Sale of homebrew is illegal in the US, the amount that may be produced each year is limited (to less than 100 gallons per adult per year), and transportation of the beer is allowed in most states, although limited to organized tastings. It is imperative that local and state restrictions be investigated and observed. Only two legal obligations exist on our campus: permission from Administration, and compliance with state and federal law. Consent was obtained from our Chancellor via an exchange of memoranda in which we explained the purpose and the rigorous controls to be imposed on the project.

Quality control (QC) session 1

The first QC evaluation session is held during the last lab session, and it lasts 1 h. Attendance is limited to students enrolled in the course and faculty or assistants actually associated with the course or with this exercise. An array of fermented foods and non-alcoholic drinks is provided for all students to evaluate (see Ref [16] for a similar activity). A handout with critical terms and concepts is distributed, with a list of the foods, the organism(s) responsible for the biochemical conversions, and the crucial biochemical pathways followed. Students of legal drinking age are offered small (~50 ml) samples of the batch. Students under legal drinking age are restricted to non-alcoholic alternatives; they are also given an invitation to return on or after their birthday.

Quality control (QC) session 2

A second QC session is held following the student session. Formally, the session is the final meeting of the Campus Safety Committee for the current academic semester; however, invitations are also extended to selected members of the campus and department administration.

Assessment/evaluation

Impact of this project on student performance was surveyed retrospectively by examination of departmental and faculty records. Student enrollment, mean grade, and grade distribution are recorded on the 'Course Grade Verification' form sent to faculty following submission of grades. At the end of each course, a departmental evaluation survey is distributed to students, who are instructed to complete, collect and return them directly to the department chairman. This 'Faculty and Course Evaluation' includes items on 'Overall Teaching Ability' and 'Overall Course Evaluation.' After the end of the semester, the faculty member receives a copy of the 'Data Tabulation and Analysis' derived from this survey, which provides the numerical results. In addition, any hand-written comments submitted by students are collected, typed and attached to this report.

Results

Retrospective surveys of student performance and satisfaction with the microbiology course indicate improvements in these areas since introduction of the brewing project. These measures include increased student enrollment, improved overall course evaluation, and improved faculty evaluation (data not shown). However, such reviews do not

control for other variables, especially intrinsic changes in the student population and parallel improvements in other aspects of this course and also in prerequisite courses. An objective, prospective analysis of the project has not yet been pursued.

Subjective analyses of the project's impact indicate increased student interest in microbiology and biotechnology in general and in industrial job possibilities in particular. Subjective measures included faculty observations and comments from the Faculty and Course Evaluation survey.

Our last significant result has been production of ten batches of beer. Of these, only one has been rated as non-consumable. The dissemination of results has provided our department with a unique avenue to showcase laboratory safety and laboratory experience for the administrative and safety personnel that oversee our daily operation.

Discussion

The fundamental approach of having students learn by doing is well-established in pedagogical research [2,24,25,28,32]; that this specifically applies to biotechnology is demonstrated by the experiences of the other authors with reports in this journal [13]. While this approach has been extensively utilized for popular topics in the form of 'genetic engineering' and 'forensic science' projects in biology courses for both majors and non-majors, relatively little has been done using other forms of biotechnology in education. Real-life scenarios pique student interest and enthusiasm; our work demonstrates that less popular topics, like metabolism, can also benefit by employing this approach.

Although improvements in such factors as interest and enthusiasm are helpful, other educational benefits can be realized. Our initial assessment of the project by objective instruments is promising but preliminary, in part due to the small class size that makes this activity possible. The microbiology course is offered once per year. Students attend common lectures and are currently divided into two laboratory sections of approximately 20 students per section. An objective, prospective survey of student performance has not been completed for the loudly articulated reason that no section has been willing to forego the experiment and serve as a control group.

A number of indicators suggest an improvement in the performance of students and perception of the microbiology course. This may be a function of other factors. There has been a 10–15% annual increase in enrollment in the microbiology course in each of the past 6 years; there has also been a 150% increase in the number of majors in our department over the past decade. In the microbiology course, both mean grade and grade distribution have shifted upwards; however, the university as a whole has been attracting better students, as evidenced by increasingly earlier closing of enrollment over the past 5 years.

Although subjective, other examples of student improvements are extensive. As noted above, students look forward to this activity. The number of substantive questions during and about this project is unparalleled. Several students have reported their independent successes in homebrewing after completing the course; over 25% of students in one section had gone on to do this within 2 years of taking the course. Students appreciate the 'ownership' of the project; they show particular interest when this activity is used as an example in lecture to compare or contrast with new examples as we progress through the various topics in the course. The project supports the core topics identified by the American Society for Microbiology for undergraduate curricula in both lecture and laboratory [3]. Students participate in a real activity. This project provides a natural topic through which one can integrate theoretical background with practical tasks, and then top it off with industrial examples and their economic impact.

The labor-intensive first session, preparing the wort and establishing primary fermentation, represents the best opportunity for hands-on activities and for the introduction of a number of basic concepts in the areas of growth limitation, nutritional requirements and abiotic factors affecting growth. The use of sanitation, but not sterilization, to provide a competitive advantage for the yeast over microorganisms is a necessary topic at this stage. Since sanitized fermentation vessels are rinsed with copious amounts of tap water, it is crucial to clarify why different limitation techniques are used, and contrast these with rigorous aseptic technique.

We have conducted laboratories using canned malt extract (hopped), dry malt extract, and whole grains. Each option has advantages and disadvantages. Use of commercial extracts (canned or dry) shortens the length of the laboratory exercise considerably. This strategy can provide more time for integrated lecture topics during the laboratory period, or allow the work to be completed within a shorter period. By beginning with intact whole grains, the clarity to the students of topics such as carbohydrate metabolism and production of fermentable sugars are easily derived and connected to previous courses in botany. Inversion of whole grains extends the work by 40–80 min (depending on method and grains used), but provides a useful demonstration of temperature-dependent enzyme activity. Prepared kits are ideal for the novice instructor and student; whole grains and complex recipes can be added in subsequent years, as the instructor becomes more familiar with the logistics of this exercise. We have used the Papazian homebrewing books extensively as a resource for timing activities and recipes [26,27]. There are a number of other good references available from homebrewing suppliers [11,17,21–23].

The second session, the transfer from primary fermenter to secondary fermenter, requires approximately 30 min. This activity can be incorporated into laboratory exercises the week following the production of wort. Alternatively, this step can be performed outside of the scheduled laboratory period, with student volunteers providing assistance. In the transfer, wort is siphoned from the primary to the secondary fermenter to minimize contamination and oxygenation. This step is optional, and the beer can be bottled directly from the primary fermenter. We perform a two-stage fermentation to improve the quality of the finished product. The 2 cm of dead yeast at the bottom of the primary fermenter provides evidence of the large number of organisms involved. A review of autolysis using the dead

yeast decomposing in the bottom of the batch provides a compelling argument to the class for completing this step.

To simplify the process of deciding when to bottle, we usually let the wort ferment until completely flat (no visible CO_2 production, SG unchanged for 3 days). We are then able to add a known amount of corn sugar [~375 g ($\frac{3}{4}$ cup) per 5 gallons wort] or dry malt extract [~625 g ($1\frac{1}{4}$ cup) per 5 gallons wort] to provide adequate carbonation within the bottles without achieving over-carbonation. If there are still fermentable sugars left in the wort at the time of bottling, the amount of carbonation in the finished product is difficult to estimate. Underestimation of carbonation potential often leads to addition of excessive amounts of sugar, excessive production of carbon dioxide and exploding bottles.

As with transfer of wort from primary to secondary fermenter, it is important to minimize oxygenation and contamination of the wort. If well planned, a class can clean bottles, sanitize equipment, transfer wort and bottle in approximately 1 h. Alternatively, we have bottled outside of the formal laboratory time. This particular activity reinforces concepts addressed previously, and so is less critical for participation of the entire class. The activity does provide a unique example of natural carbonation as a method of product preservation and for limitation of oxidation. After bottling, the beer is stored at 15–20°C (55–65°F) for 3 weeks to 2 years.

We have established a routine of moving the beer off campus at the time of bottling to establish absolute control over the product. This strategy has proven to be an effective means of securing and maintaining support of administrators for this exercise as a classroom activity.

We must mention two sobering legal issues. The first, the legality of producing an alcoholic beverage is not a problem in Wisconsin. Federal law permits production of alcoholic beverages by individual homebrewers (or winemakers) [4]; however, state laws vary. Eight states (Alabama, Idaho, Iowa, Kentucky, Mississippi, Ohio, Oklahoma, and Utah) have laws that prohibit production of beer by anyone other than licensed commercial breweries; six other states (Louisiana, Maine, Nevada, New Mexico, New York, and West Virginia) have laws that are unclear regarding unlicensed brewing [5]. Local laws may place further restrictions on production, possession, transportation, and consumption. Campus and local police are well informed and can provide all necessary statutes on this topic; the American Homebrewers Association also tracks this information nationwide [5].

The issue of student age is significant everywhere; we strictly enforce the laws of our state as part of the agreement to allow students to taste the product. We are lucky; most of the students are juniors or seniors and already of legal drinking age when they take the microbiology course. Of those who have not been of legal age at the time of testing, about half have returned after their birthday for a sample from the labors of a subsequent class.

The other serious legal issue is that of student and administrative perception. We have also been fortunate here, due in no small part to the tone we set throughout the project. At any suggestion of impropriety we clarify that this is not an excuse to party; this is an academic project. The fermenters are kept in a locked cupboard. Once the beer is bottled, it is transferred off campus and aged in a residential basement. Only the amount of beer required for the QC sessions is returned to campus, and only on the day of the testing, not before. Attendance at the evaluation session is limited to enrolled students and faculty involved in the course. Food and non-alcoholic beverages are provided in abundance. Each student of legal drinking age may taste each batch; a faculty member distributes only a small quantity to the student. This high level of security and ubiquitous control is a key reason why our Chancellor agreed to initial and continued support of the project. We also host the Campus Safety Committee's final meeting, as a luncheon, and give these individuals an opportunity to evaluate the year's batches. To this function, we also extend invitations to departmental and campus administrators who were curious about the proceedings. The same rules apply here—restrictions are presented and must be observed.

Finally, the project has provided avenues for discussion of current issues, such as the interpretation of the Reinheitsgebot with regard to genetic engineering [33]. In 1516, Wilhelm IV of Bavaria established a purity law, 'der Reinheitsgebot,' which prohibited brewers the use of any ingredients other than water, barley malt, hops, and yeast. Alteration of the yeast to decrease the brew time seems a minor infraction of this tradition. More ominous to German tastes is the alteration of the yeast and the plants, singly or in concert, to add flavors to the final brew. This also contrasts strikingly with production of lambic beers in Belgium, in which inoculation of the wort with the endemic microbiota is essential [14].

Our experiences have gone beyond field trips to the local microbrewery; we have had students pursue independent research projects with a practical twist. One student, working with the local microbrewer, examined potential sources of contamination and compared different cleaning regimens, providing a full-bodied experience for both of them.

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