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Group-Effort Applied Research (GEAR): Expanding Opportunities for Undergraduate Research Through Original, Class-Based Research Projects

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Abstract

Undergraduate research clearly enriches the educational development of participating students, but these experiences are limited by the inherent inefficiency of the standard one student - one mentor model for undergraduate research. Group-Effort Applied Research (GEAR) was developed as a strategy to provide substantial numbers of undergraduates with meaningful research experiences. The GEAR curriculum delivers concept-driven lecture material and provides hands-on training in the context of an active research project from the instructor's lab. Because GEAR is structured as a class, participating students benefit from intensive, supervised research training that involves a built-in network of peer support and abundant contact with faculty mentors. The class format also ensures a relatively standardized and consistent research experience. Furthermore, meaningful progress toward a research objective can be achieved more readily with GEAR than with the traditional one student - one mentor model of undergraduate research because sporadic mistakes by individuals in the class are overshadowed by the successes of the group as a whole. Three separate GEAR classes involving three distinct research projects have been offered to date. In this paper, we provide an overview of the GEAR format and review some of the recurring themes for GEAR instruction. We propose GEAR can serve as a template to expand student opportunities for life science research without sacrificing the quality of the mentored research experience.

Keywords

laboratory; mentoring; molecular biology; training; undergraduate research

INTRODUCTION

Students with research experience are more likely to graduate with a STEM degree and to apply their skills in the workforce or post-baccalaureate programs [1–3]. These outcomes are likely related to the confidence and lab skills gained from an undergraduate research experience [3–6]. Unfortunately, the traditional one student - one mentor model of undergraduate research can restrict the utility of hands-on training to a few select students.

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The Burnett School of Biomedical Sciences at the University of Central Florida (UCF) in Orlando has been developing novel lab-based classes to meet the growing need for real-world laboratory training [7, 8]. The Burnett School recently implemented a Group-Effort Applied Research (GEAR) program that expands undergraduate opportunities for participation in an original research project by improving the efficiency of a mentored research experience. In GEAR, a single research-active faculty member supervises up to 15 students on a project from the instructor's lab. The cohort of students receives didactic instruction on core concepts in molecular biology, basic principles of common laboratory methods, and discipline-specific information related to the research project. Students also receive supervised training for relevant laboratory procedures. This knowledge is then applied in the laboratory as students prepare, execute, and interpret experiments linked to an aspect of the instructor's research program. GEAR is designed as a single semester experience that can provide substantial numbers of students with meaningful research experiences. The course has also served as a springboard for independent student projects and has provided tangible results for the instructors' research programs. Here, we describe the GEAR curriculum and our experiences from the first three offerings of the course. We propose GEAR can serve as a template to expand student opportunities for life science research without sacrificing the quality of the mentored research experience.

COURSE ORGANIZATION AND CONTENT

Undergraduate research has proven benefits for the educational experience, but the current paradigm of research training (i.e., a one student - one mentor match) presents significant limitations to science education: it is inherently inefficient as it can serve only a small fraction of the student body, highly variable in student and project outcomes, and often lacks the crucial aspect of peer support [5, 6, 9–11]. GEAR is designed to address these limitations and can accordingly provide a substantial cohort of undergraduates with meaningful one-semester research experiences. The GEAR format delivers concept-driven lecture material and provides hands-on training in the context of an original project related to the instructor's research interests. Because GEAR is structured as a class, participating students benefit from intensive, supervised research training that involves a built-in network of peer support and abundant contact with faculty mentors. Extensive faculty contact and peer support networks have been linked to increased student satisfaction and success in research programs [1, 2, 4, 12]. Furthermore, the class format ensures a relatively standardized and consistent research experience. GEAR also improves the economy of student training, as a single instructor can effectively mentor up to 15 students at a time. Finally, class practicals and examinations allow students to objectively assess their progress in conceptual knowledge and technical skills. Thus, the structure of GEAR potentially offers numerous advantages over the conventional one student - one mentor model for undergraduate research (Fig. 1).

For a typical GEAR course, an instructor would identify a component of his/her own research that could benefit from student participation. This represents a major challenge for GEAR development, as it must be possible for inexperienced students to reach a project goal in the single semester time frame of the class. The organization of the research experience must also be flexible enough to accommodate occasional setbacks in the experimental design/execution. Some failed experiments should be expected, but this is acceptable. In fact, it is a normal part of research that students should be aware of. It should be noted, however, that intermittent mistakes by individuals in the class will be overshadowed by the successes of the group as a whole (Fig. 1). Thus, meaningful progress toward a research project should be more apparent with GEAR than with the traditional model of undergraduate research. Research groups of 2–3 students are given overlapping sets of experimental samples in order to increase the *n* value and to verify the overall class results. For example, team #1 is given samples A, B, and C; team #2 is given samples B, C, and D; and team #3 is given samples C, D, and A. If each team obtains the same result for the same sample in this strategy, then the faculty supervisor can be confident of the result. At times, it will be necessary to develop a single reagent or perform a single experiment that is essential for continuation of the project. All students will be assigned the same task at the same time when these bottlenecks occur. At least one research team is likely to successfully complete the bottleneck step, so the resulting product can be transferred to the rest of the class. By having students work on overlapping sample sets and by focusing class-wide attention on potential project bottlenecks, the GEAR format should facilitate steady progress towards research objectives. Advances made in the semester-long class can then be carried forward in the next GEAR offering (Fig. 2).

GEAR students receive didactic instruction in addition to laboratory training. These lectures are followed by hands-on applications in the lab. All GEAR projects emphasize basic techniques in molecular biology, but most participating faculty members will have distinct research interests and areas of expertise. The exact content of GEAR lectures will accordingly vary from section to section and will depend upon the research interests of the GEAR instructor. In all cases, the goal of the lecture/lab exercises is to provide students with a strong fundamental understanding of how a lab functions, both in terms of relevant experimental methods and the day-to-day operation of a research laboratory. Syllabi for the three GEAR courses offered to date are provided as Supporting Information (Appendix A).

GEAR was predicated, in part, on a report involving a research class of four undergraduates with previous exposure to basic molecular biology techniques [13]. These students worked 15 hours per week on parallel but independent genetic projects, and they received group instruction over the 10 week span of the course. GEAR presented additional challenges to this format, including (i) a larger class size; (ii) students with no background in molecular biology; and (iii) more diverse, complex projects. Graduate and undergraduate teaching assistants were recruited to help manage the course, but GEAR students were responsible for all aspects of the project (making solutions, pouring gels, cleaning glassware, etc.) and not just the experiment itself. GEAR represents a general framework for supervised research experiences that can be adapted to different projects, goals, and student populations. Below, we provide a description of the three GEAR classes offered to date and ruminate on common themes for GEAR instruction.

GEAR EXPERIENCES

Overview of Dr. Moore's GEAR Projects

Dr. Moore developed a new project in his lab that relies on piecemeal contributions from newly-trained undergraduates. The project goal is to uncover the roles of a set of conserved prokaryotic genes of unknown function, the so-called "orphan" genes. Undergraduates in the Moore lab developed a new targeted protein degradation system that allows for the rapid depletion of selected cellular proteins [14]. The GEAR project goal is to use this degradation system to investigate the function of a subset of the orphan genes. The first phase of the GEAR project required the generation of a series of new bacterial strains with modified target orphan genes for use in subsequent degradation studies.

Undergraduate contributors working in the lab outside of the GEAR class were teamed to align complementary class schedules such that experimental procedures requiring several consecutive hours or days were feasible. Several undergraduate teams were organized, with each team assigned to different tasks in the development of the degradation system and its testing on proteins with established functions. This approach allowed each team to develop a sense of ownership for their project component. Another important aspect of the GEAR project was the relatively simple conceptual design of the work: allowing students to clearly explain the project and its importance to their non-science peers (or parents), thereby providing additional empowerment and motivation for the students.

As the GEAR class concept came to fruition, several students working on the project participated by pre-evaluating experimental procedures planned for the course. These experimental dry-runs ensured that reagents and equipment were in order. Perhaps more importantly, these students were members of the first GEAR class, so there was a pre-developed sense of feasibility in the experimentation. After the first summer class (described below), three GEAR participants transitioned to the next phase of the project and served as undergraduate teaching assistants (UTAs) to oversee group efforts in the second GEAR offering. Thus, a "pay-it-forward" system from trainee, to experimenter, to instructor was developed as a self-sustaining training infrastructure (Fig. 2). These students also served as approachable experts who helped dissolve the perceived boundaries between students and instructor.

Dr. Moore: Summer 2012 GEAR

The experimental goal of the first GEAR course was to generate a collection of new bacterial strains (10 total) to be used in the orphan gene project. GEAR was announced in several lecture courses, and applicants were screened with a quiz and personal interview (see Supporting Information; Appendix B). Selected students ranged from freshman with no lab experience to seniors with multiple lab experiences. All students were majoring in either Biotechnology or Molecular Biology and Microbiology, which are the two UCF degree programs that focus on molecular biology. Each GEAR student was assigned to a three-member team with tiered experiences and math proficiencies. An effort was made to ensure that each team had at least one math-proficient student because each team was not permitted to begin their experimental work until they correctly calculated their reagent formulas. Two students had already contributed to the project and were familiar with the techniques were also included in the group of 15 total GEAR students. Before and during the GEAR class, these pre-trained students were tasked with running through protocols and also following up on experimental steps that required attention between classes.

This first GEAR course covered a 12 week summer term and was held in the lab space used for one the department's core training labs in quantitative biological methods. The lab contained basic molecular biology equipment, (pipettors, electrophoresis boxes, incubators, scales, pH meters, thermal cyclers, *etc.*). The lecture and class was scheduled during times when the space was not in use by other groups. The course had a one hour lecture in the afternoon prior to the day of the lab session, which met once per week for ~3–6 hours. These lectures covered the project goals, the experimental outlines, technical aspects of the way equipment works, and typically provided a small take-home assignment such as calculating the recipe components needed for the next day's experiments (Table I). There was also a brief lecture period before each lab session to go over the experimental details or to quiz students on aspects of the assignments.

Students began their training by learning to properly maintain a notebook (one per team), calculate chemical formulations, to use scales and pH meters, and to properly pipette. They concomitantly prepared reagents from scratch that they would need for the project (gel buffers, DNA purification reagents, bacterial growth media, *etc.*). Experimental tasks were then performed in synchrony according to the GEAR mechanism. Applied techniques included casting and running agarose DNA gels, calculating and mixing polymerase chain reactions (PCR), purifying DNA for sequencing, electroporating bacteria and plating to select recombinants, PCR colony screening, preparing bacteriophage lysates, and moving the newly-modified orphan genes to experimental hosts (Table II).

A laboratory practical at the end of the course required students to calculate and prepare replicate dilutions of a provided stock sample of caffeine. The accuracy and precision of each student's work was then determined using a spectrophotometer to measure caffeine absorbance. In most cases, correlating experimental success with performances on the skills practical allowed the identification of weak areas that should be addressed to improve lab performance. The first GEAR class generated all 10 of the intended orphan gene modifications within six weeks. By the end of the semester, each modified gene had been moved to test strains and re-verified. Based on the productivity of individual students working on the project in the Moore lab prior to the class, this accomplishment would have taken more than two semesters with a well-trained and dedicated undergraduate. Moreover, six of the GEAR students joined Dr. Moore's lab to continue the project during the following semester. Three of those students became teaching assistants for the subsequent GEAR class (described below). GEAR undergraduates working on this project generated all of the data for two peer-reviewed publications [14, 15] and for a funded NIH grant (NIH 1R15GM102714-01). Student evaluations obtained from the standard end-of-semester UCF survey on Student Perception of Faculty Instruction were highly favorable (5 out of 5 index score, Supporting Information; Appendix C).

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Dr. Moore: Summer 2013 GEAR

By the next summer, the orphan gene project had advanced to a stage that required quantitative, real-time PCR (qPCR). Using the strains generated in the first GEAR class, students that continued on the project following the first GEAR class established the expression of the modified target orphan genes and prepared RNA from test cultures. The class goal was to quantify the levels of selected mRNAs and to validate the performance of the qPCR reagents. Dr. Moore had recently published a new qPCR analysis method [15], and a departmental colleague who had never performed qPCR needed to use the technique for his research. Thus, this GEAR class focused on training students in conventional and advanced qPCR techniques that could be used to process the colleague's experimental samples as well as the project samples from the Moore lab (Tables I and II). The colleague served as a co-instructor for GEAR and gained qPCR training himself. Thus, the GEAR format provided a powerful mechanism to cross-pollinate research laboratories and to promote experimental cohesion between investigators with different training backgrounds.

This GEAR class of 12 students and 3 UTAs was able to analyze more than 16 different experimental samples in triplicate. Moreover, each student (and the co-instructor) learned the principles behind conventional and advanced qPCR analyses. Each was able to analyze raw qPCR data by hand using spreadsheets, which freed them from the dependence on the "black-box" software provided by the machine's manufacturer. Also, because this class had more exposure to small volume reagent mixing, their pipetting skills were generally excellent, as determined by the pipetting practical. The notebooks from the preceding summer's GEAR course were used again by the new teams so the students relate to the work that went into the project by their peers. Evaluations from the Student Perception of Faculty Instruction survey were again strong (index score of 4.83 out of 5, Supplemental Material; Appendix C).

Overview of Dr. Teter's GEAR Project

The Teter lab studies host-toxin interactions involving cholera toxin (CT), a virulence factor produced by *Vibrio cholerae* that generates the profuse watery diarrhea of cholera. In order to generate a toxic effect, the catalytic CTA1 subunit must be separated from the rest of the multimeric toxin. This event is facilitated by protein disulfide isomerase (PDI), a host oxidoreductase and chaperone [16]. GEAR students were placed on a project to identify the region of PDI that interacts with CTA1. We began the semester with eleven expression plasmids that encode different regions of PDI. Students were assigned overlapping subsets of PDI constructs to purify and screen. In the 15 week time frame of the course, the GEAR students (i) amplified and purified all plasmids; (ii) transformed each plasmid into *E. coli* BL21(DE3)pLys; (iii) purified six His-tagged PDI constructs; and (iv) began the process of protocol optimization for a co-immunoprecipitation assay to detect the interaction between CTA1 and the PDI proteins. These activities required the students to learn and apply a number of techniques in molecular biology such as transformation, plasmid preparation, and Western blotting (Table II). Students only handled the purified CTA1 subunit, which, in the absence of the cell-binding component of the toxin, is essentially non-toxic. In addition, an early class session was reserved for the standard UCF laboratory safety course that was delivered by a representative from our Environmental Health and Safety Department.

Dr. Teter: Fall 2012 GEAR

Seven sophomores majoring in either Biotechnology or Molecular Biology and Microbiology were enrolled in this GEAR class. Sophomores were specifically targeted for enrollment because research experiences beginning in the second year of college have the greatest positive impact on student retention in the major [1]. None of the GEAR students had completed any upper-division coursework, and none of them had previous experience in a research lab. This GEAR course was not advertised to the general student population, so all seven students heard about the offering from word-of-mouth and personally requested a position in the class. Otherwise, the students were not pre-screened for enrollment. Three students were interested in medical school, one student was interested in dental school, one student was interested in becoming a medical examiner, and two students did not have defined career plans.

This GEAR class met from 3:00 – 5:00 on Mondays, Wednesdays, and Fridays in a temporarily vacant research lab adjacent to the Teter lab. Holding GEAR in a research facility (as opposed to a teaching lab) emphasized the actual culture of the research environment and allowed students to interact with members of the Teter lab. It also ensured all necessary equipment and reagents were readily available and facilitated project maintenance outside of regular class hours. Each week began with didactic instruction on topics such as lab math, cholera, antibodies, and protein expression (Table I). The original lecture plan was designed to match the planned experiments for the week, although adjustments based on research progress had to be made over the course of the semester. Various lab manuals, textbooks, and company websites were used as source material for the lectures, which were delivered in a conference room near the GEAR lab. This allowed easy transition between the lecture and lab. In some cases, lectures were held between incubation steps rather than at the beginning of class. Methods-related instructional content (micropipetting technique, the purpose each step in a plasmid preparation, *etc*.) was also reinforced or introduced informally in the lab. In addition to Dr. Teter's input, the students received supervision and instruction from **Helen Burress**, a graduate teaching assistant (GTA) working in the Teter lab. A new laboratory manual released in fall 2012 covers most of the GEAR lecture material; this "Biotechnology: A Laboratory Skills Course" textbook from BioRad will likely be used as a core manual for future GEAR classes.

A certain degree of flexibility was required to advance the course/project goals. For example, when the students had difficulty preparing competent *E. coli*, we purchased electro-competent *E. coli* from a vendor the students had identified from a homework assignment. We also found by Western blot analysis with anti-PDI and anti-His antibodies that only six of the eleven PDI constructs provided for the project were His-tagged, although we were told all eleven were His-tagged. This emphasized the value of preliminary control experiments and focused our purification efforts on the six His-tagged proteins. We initially planned on using Talon affinity chromatography to pull down complexes of PDI-His_6 and CTA1, but additional control experiments demonstrated untagged CTA1 binds directly to the Talon resin. This forced us to pursue a co-immunoprecipitation strategy, and the semester ended with the students working on optimization of this protocol with CTA1 and full-length PDI-His_6. A focused effort on lab math, proper pipette use, and preparation of

SDS-PAGE gels was required at the beginning of the semester. However, student-led preparatory work was not an impediment to research progress.

Grades were derived from three examinations (including the final exam), participation in the lab (including keeping a proper **paper** notebook), and homework assignments such as calculations of lab math (molarity, dilutions, standard deviations, etc.). The exams tested student knowledge of lab math, molecular biology techniques, and basic background information related to the project. We initially planned on administering graded lab practicals as well, but we realized this was unnecessary due to the focused hands-on training in lab techniques and the need for proper lab skills to move the project forward. The planned lab practicals were therefore folded into the lab participation points, which accounted for 50% of the class grade. Examinations accounted for 44% of the class grade, and homework assignments accounted for 6% of the grade.

Enthusiasm for the course increased noticeably as students became comfortable in the lab and made demonstrable progress in their work. Each student received individual attention in both the lecture and lab components of the class, which allowed them to make rapid conceptual and technical gains. Some students were more comfortable seeking advice and help from the GTA than Dr. Teter. The GTA, a 4^{th} year Ph.D. student, thus served as an additional mentor for the class. The GTA also provided invaluable assistance outside of regular class hours with activities such as inoculating cultures the day before class, starting initial centrifugal spins before class, and finishing the final step of a protocol after class. GEAR students were theoretically responsible for all aspects of the project, but these GTA-led activities were necessary to keep the course on a reasonable pace. Interestingly, as the semester progressed, GEAR students would arrive to class early, stay late, or show up on off-days to help with these activities. GEAR students thus appeared to be invested in their work, viewing their experience as more of a research project than a class assignment. Student evaluations of the course indicated a high level of satisfaction, especially with the opportunity to be exposed to a realistic, hands-on research experience (Supporting Information; Appendix C).

Six of the seven GEAR students returned to the Teter lab in the spring semester to continue their work as an independent project. However, progress stalled in the first half of the spring semester. Students had lost confidence in their skills over winter break, and this problem was compounded by the lack of immediate, direct supervision for an independent research project. There were also communication problems: each student kept a separate schedule, and they were often unclear on what their lab mates had done earlier in the week or needed done later in the week. This made it difficult to coordinate group efforts on a single goal. These problems were rectified in the second half of the semester and highlighted the strengths of the GEAR format, which provides multiple students with a structured environment involving constant reinforcement of core concepts and techniques. GEAR can thus engage students with a realistic view of the research enterprise, but continued experience and supervision may be necessary for students to maintain their confidence and technical skills. Lasting benefits of GEAR participation appear to include a continued interest in research, as four of the seven GEAR students participated in summer 2013 research experiences at UCF, Sanford-Burnham Medical Research Institute, Moffitt Cancer Center, and Oak Ridge National Laboratory.

RECURRING THEMES FOR GEAR INSTRUCTION

A major challenge for GEAR instruction involves the design of a project that can be completed in one semester by a cohort of students working on parallel tasks. Classes can be designed around stand-alone projects or may be a component of ongoing investigations. The goals should be commensurate with student experience, and we have had success with both unselected and selected student populations. The flexibility of the GEAR format allows each instructor to tailor a project that meets the needs of his/her research program. Other advantages to the faculty instructor include training future lab members, supporting graduate students with a GTA related to the dissertation project, fulfilling a teaching assignment while advancing the research program, and the potential to establish collaborations with faculty colleagues.

GEAR requires the faculty instructor to adapt to the changing circumstances of the project. As with most classes, the majority of effort for GEAR goes into the planning and design of the course. However, due to the nature of research, changes need to be made in the GEAR structure on a week-to-week basis. These adjustments do not require substantial effort because the topic is directly related to the instructor’s area of expertise and research program.

Frequent faculty-student contact allows the GEAR instructor to adjust course content on the fly and to accurately assess individual student ability. Frequent contact is also essential for a properly mentored research experience that engages the students and encourages them to take ownership of the project [17]. Although GEAR is organized as a one semester class, it can provide students with a realistic view of the research experience and, often, their first in-depth interaction with a faculty member. Many students have remained in contact with their GEAR instructor and have been motivated to seek new, independent research positions. GEAR thus serves as an effective, guided entry into undergraduate research.

EXPANSION OF THE GEAR FORMAT

GEAR is not designed around a single defined project, so its format can be adopted by any research-active faculty member. Furthermore, instruction of a GEAR class allows faculty members to potentially advance their research program while simultaneously fulfilling their teaching obligation. Additional faculty members have accordingly expressed an interest in the GEAR format. GEAR classes led by different faculty would have different research goals and instructional content, so, in the future, students may be able to enroll in multiple GEAR courses or pick a specific class matching their research interests. Faculty have also discussed the possibility of a "High" GEAR class which would recruit upper-division students with molecular biology training to more advanced projects that could be processed in parallel by a larger cohort of 20–30 undergraduate researchers. This GEAR variant would likely require graduate and/or undergraduate teaching assistants as well as tiered three-member student teams containing at least one experienced undergraduate researcher. Other variations of GEAR could be used to train high school science teachers or to specifically train undergraduates in targeted skill sets useful for entry-level employment in the biotechnology workforce. Finally, faculty colleagues in the UCF College of Sciences have considered adapting the GEAR format to other disciplines in science, technology, engineering, and mathematics.

CONCLUSION

There is a critical need to provide students with practical research training, but it is impossible to meet this need with the traditional one student - one mentor model of undergraduate research. In contrast, the GEAR format has the potential to generate increased research opportunities for substantial numbers of students. GEAR is designed as a single semester experience, but its unique format will ensure students receive effective hands-on technical training in the context of an original research project. GEAR participants will also obtain an accurate, first-person view of the research environment. Furthermore, the economy of GEAR training will allow many undergraduates to gain some research experience. Most of these students would otherwise have no research experience at all. Students could possibly gain additional expertise by repeated enrollment in GEAR; the distinct projects offered by different GEAR faculty will eliminate redundancy in course content and allow students to gain a range of research experiences. GEAR is now an official course offering at UCF (MCB 4920C) that has received a high level of interest from both students and potential faculty instructors.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

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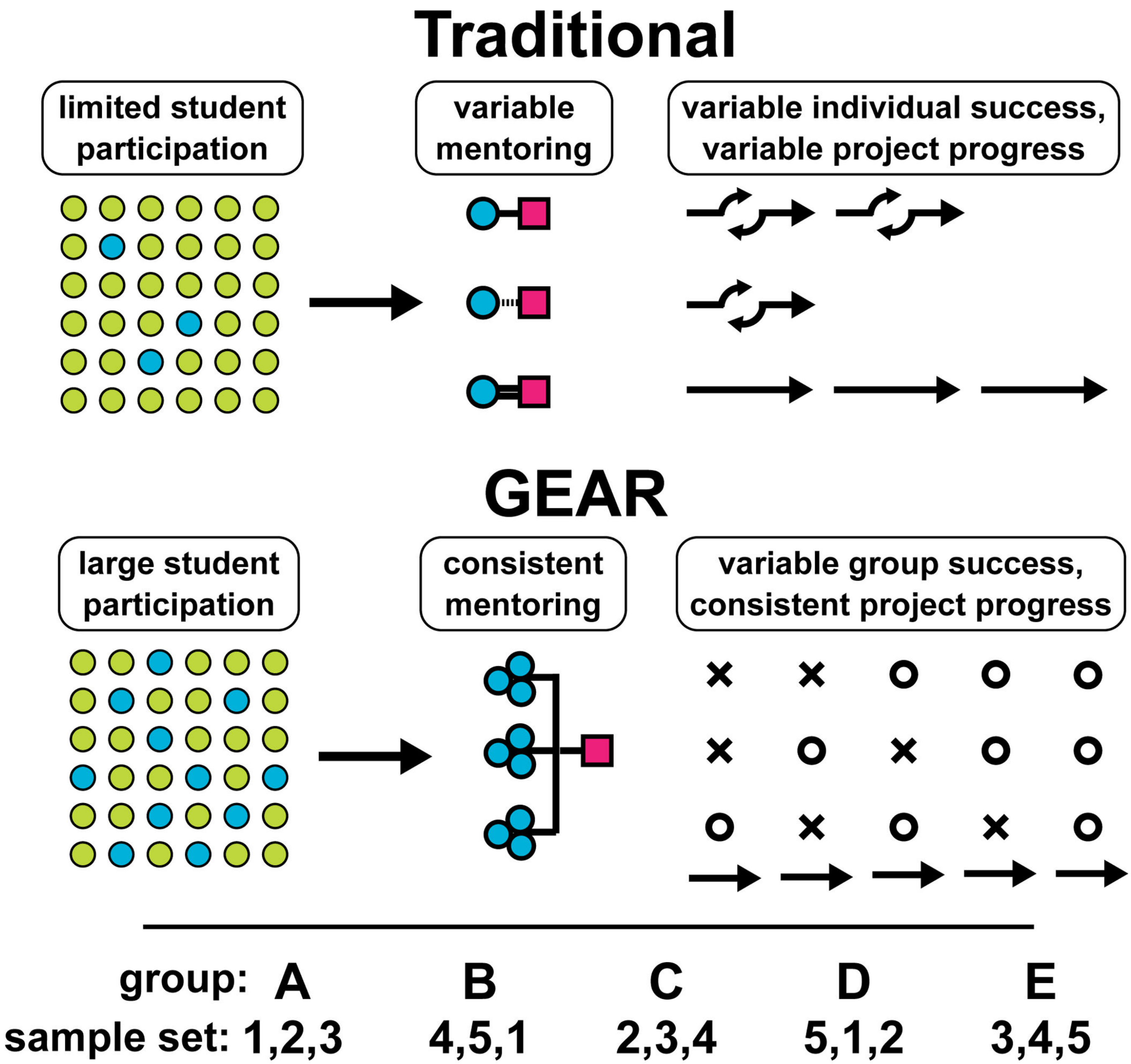

Fig. 1. Traditional and GEAR training methods

Numerous students require research experience (colored circles). TOP PANEL: In the traditional one student - one mentor model of undergraduate research, the available faculty and laboratory space greatly limit the number of students selected for research projects (blue circles). Different mentors (red squares) then offer variable levels of guidance and training to their students. Project progress (straight arrows) is hampered by individual experimental failure and multiple repeats of the same task (curved arrows). BOTTOM PANEL: In GEAR, a large number of students are selected from the student body and placed in small groups under the guidance of a single mentor. All students receive consistent guidance from that mentor. In addition, students receive standardized guidance and training from the lecture content of GEAR. In the research component of GEAR, experimental failures by individual groups (represented by an x) do not restrict progress of the project as a whole. Successful groups (represented by an o) distribute products to failed groups, and the whole class moves to the next task. Individual groups receive overlapping sample sets in order to increase the *n* value and to verify the overall class results.

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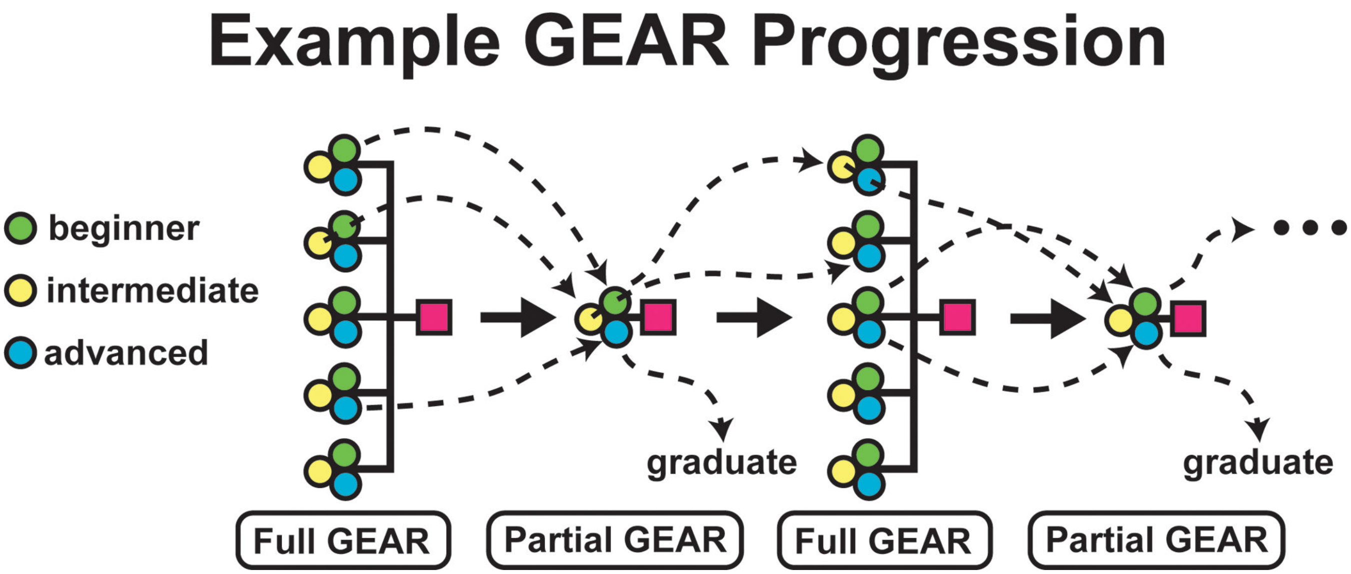

Fig. 2. The GEAR carry-forward strategy

GEAR groups are assembled to contain a beginner, an intermediate, and an advanced student. Typically, beginners with strong mathematics skills are teamed with more lab-experienced, "advanced" students. This arrangement allows for confidence-building for the beginner (by demonstrating they can out-perform other team members), while at the same time strengthening the group performance. Full GEAR classes contain multiple groups working in synchrony according to Figure 1. After the semester, interested students continue to work on, and advance, the main project in the instructor's lab. As experienced GEAR students cycle out of the project (graduation), they are replaced by new GEAR students who have advanced from their prior experience. Importantly, GEAR students working full-time on the project serve either as group members or teaching assistants in future Full GEAR sessions. A GEAR student can contribute to the project for a single semester or for several years.

Table 1

GEAR Lecture Content.

Moore summer 2012 class	Moore summer 2013 class	Teter fall 2012 class
Introduction, Lab Safety, and Lab Notebooks	Introduction	Cholera, Laboratory Materials and Safety
Molarity and Buffers	Molarity, Buffers, and DNA electrophoresis	Lab Notebooks, Lab Math
PCR and Primer Design	pH, Weight, Charge, and Electricity	Aseptic Technique and Bacterial Growth
Electroporation, Plating, and Bacterial Growth	DNA and PCR	Protein Structure and Function
Recombination	Quantitative, Real-Time PCR	Plasmid-Based Gene Expression
Sequencing	Quantitative PCR: Methods of Data Analysis	SDS-PAGE and Western Blot
Bacteriophage and Transduction	cDNA preparation from RNA	Antibodies and Epitope Tags
Plasmids and Transformation		Protein Expression and Purification
		PDI, CT, and Protein Folding

Table 2

Techniques Applied in GEAR.

Moore summer 2012 class	Moore summer 2013 class	Teter fall 2012 class
Lab safety	Lab safety	Lab safety
Aseptic technique	Aseptic technique	Aseptic technique
Pipet-Aid / pipetman use	Pipet-Aid / pipetman use	Pipet-Aid / pipetman use
Lab math	Lab math	Lab math
Lab documentation	Lab documentation	Lab documentation
Use of balances and pH meter	Use of balances and pH meter	Use of balances and pH meter
Plasmid preparations	Agarose gel electrophoresis	Plasmid preparations
Bacterial plating and culturing	Conventional PCR	Spectrophotometry
Recombineering	Use of Excel for modeling PCR	Transformation by electroporation
Spectrophotometry	Quantitative, real-time PCR	SDS-PAGE
Transformation by electroporation	cDNA preparation from RNA	Western blot
Agarose gel electrophoresis		Dialysis
Preparation of electrocompetent *E. coli*		Bradford assay
Transduction		Talon affinity chromatography
PCR		Pull-down assay
		Co-immunoprecipitation