DEVELOPING LEARNER-CENTERED FUTURE FACULTY: FIRST IV – A UNIQUELY EFFECTIVE PROGRAM OF PROFESSIONAL DEVELOPMENT

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Abstract
Challenges in training faculty in inquiry-based, learner-centered instruction include empirically evaluating the efficacy of training in teaching and sustaining long-term support for change. We developed the Faculty Institutes for Reforming Science Teaching (FIRST IV) model to provide new approaches to professional development in biology instruction for postdoctoral scholars. The goal was to develop early-career faculty who value and implement evidence-based pedagogies that facilitate learning. We report the activities and outcomes of FIRST IV, using comprehensive evidence derived from expert reviews of participants' teaching, self-reported data from participants and students, and comparisons with non-project faculty. Participants completed a workshop twice in two years, followed by teaching an entire or partial course at their institution and sustained mentoring by STEM education experts. Postdocs showed belief in learner-centered teaching, and 74% taught using primarily learner-centered practices. We followed a subset of participants into their first faculty positions and quantified how their instructional design and student assessments differed from a colleague at the same institution. External review of teaching indicated that FIRST IV faculty practiced significantly more learner-centered instruction and used more collaborative learning than their colleagues. We conclude that the FIRST IV model offers significant and unique contributions to current challenges in professional development in STEM education

I. Subject/Problem Introduction

In recent years, the growing emphasis on improving the state of undergraduate education in the sciences (e.g., Anderson et al. 2011, Brewer and Smith 2011, President's Council of Advisors on Science and Technology 2012, Association of American Universities 2014) calls for a transformation of undergraduate science courses. The transformation of STEM education requires a fundamental change in how college instructors approach teaching and learning, moving from a teacher-centered to a learner-centered model (Weimer 2002). In response, professional development workshops have been widely available for decades and represent a common venue for instructors to think about and engage in questions related to teaching and learning. Despite the availability and interest in these professional development opportunities, there is little evidence of resulting widespread change in teaching practice (Garet et al. 2001, Gibbs and Coffey 2004, Henderson et al. 2011, Henderson et al. 2012). Thus, there is a continued need for new models of professional development that result in transformed teaching by participants.

Describing outcomes of professional development initiatives objectively is critical to developing best teaching practices that ultimately improve learning by students in science classrooms. Rigorous assessment of professional development programs is particularly important since even instructors with the best of intentions often do not implement the teaching strategies that they learned in workshops, yet report doing so (e.g., Ebert-May et al. 2011). The availability of reliable evidence for teaching practice after professional development is limited across STEM disciplines, making the identification of "best practices" and effective change models challenging (Henderson et al. 2011, Amundsen and Wilson 2012). To date, the majority of professional development programs and workshops are evaluated through self-report surveys that focus on participant satisfaction and perceived learning only (e.g., Pfund et al. 2009, Ebert-May et al. 2011). Rigorous evaluation of what participants learned during a workshop and what type of teaching they implement post workshop is largely unavailable in the literature (Connolly and Millar 2006), particularly with regard to independent assessment of classroom practice that supports self-reported data.

We designed a professional development program with the goal of developing future biology faculty who value and implement evidence-based pedagogies to facilitate student learning. In response to the need for empirical evidence that a professional development program is effective, we incorporated rigorous evaluation methods that use self-reported data from the participants and external observation and analysis of their teaching while participating in Faculty Institutes for Reforming Science Teaching (FIRST). In developing FIRST, we selected implementation strategies based on scientific teaching research (Handelsman et al. 2004), findings from the conceptual change literature, and outcomes of a previous FIRST program.

The challenge of creating instructional change in higher education and understanding how to promote such change has been a topic of much conversation (e.g., reviews by Emerson and Mosteller 2000, Henderson et al. 2011). The educational reform effort requires a fundamental shift in how the instructor conceives the learning and teaching experience, as described by conceptual change theories (e.g., Posner et al. 1982, Pintrich et al. 1993, Feldman 2000). In order to produce transformed educational practices, it is important that instructors are dissatisfied with teaching practices and recognize the importance of change (Gess-Newsome et al. 2003).

What strategies, then, can promote educational transformation? Henderson et al. (2011) concluded, after an exhaustive review of the instructional change literature, that effective change strategies must leverage instructor beliefs, employ long-term interventions (>1 semester), and work within the complex dynamics of colleges and universities. Additionally, Emerson and Mosteller (2000) determined that successful change strategies are collegial, use coordinated efforts over an extended period of time, and are focused and concrete. Henderson et al. (2011) also concluded that the "state of change strategies applied to undergraduate STEM instruction is not strong...new work often does not build on prior empirical or theoretical work; and most published results claim success of the change strategy studied, but the evidence presented is often not strong" (pg. 977).

We designed the FIRST program to fill these gaps in design and program evaluation. Our goals were to develop an improved professional development model and to provide evidence for its effectiveness at transforming teaching practice. Through our program we helped future biology faculty learn and/or improve their use of evidence-based teaching strategies and fostered instructors who value and implement learner-centered teaching. The program design leveraged many of the change strategies identified above: specifically, the program was built on a mentored, team-based approach to learning in which participants engaged in an iterative process of materials development and implementation in the classroom, followed by reflection and revision. Importantly, we paired this process with a strong focus on objective data collection, in order to evaluate the success of the program.

II. Design/Procedure

The subjects of the FIRST program were 201 postdoctoral scholars (PDs). We recruited participants nationally in 2009 and 2011 to form two separate cohorts of 99 and 102 PDs respectively. All protocols used in the FIRST project were approved by the Michigan State University Institutional Review Board (IRB #X08-550 Exempt, Category 2). To begin, each cohort participated in a four-day training workshop in which they began the process of developing an entire introductory biology course, while concurrently learning about learner-centered teaching pedagogy and practices, course design, and assessment. During year 1 for each cohort, teams of PDs continued to develop their introductory biology course and completed at least one teaching experience, consisting of an entire college-level course or part of a course taught with other faculty. At the beginning of their second year, each cohort participated in a three-day training workshop that focused heavily on reflection on teaching experiences that occurred in year 1 and further development of learner-centered teaching practices and course design. During year 2 the PDs continued to refine their introductory course and again completed at least one teaching experience. Throughout their project participation PDs worked in teams, each of which had an assigned mentor who was an expert in STEM pedagogy and teaching. The mentors provided feedback about teaching, development of courses and teaching materials, and job applications. Each PD team scheduled meetings with the mentor as needed.

Research Question 1: To what extent was the program effective at developing PDs who taught using learner-centered, inquiry-based approaches? The effectiveness of the professional development program was determined using a mixed methods analysis. We compiled data from three sources: 1) self-report data from the PDs and students about the instruction and classroom environment, 2) external expert review of teaching videos of courses taught by PDs, and 3) data obtained from some PDs once they gained employment in a full-time teaching position.

We characterized the PDs' beliefs about their own teaching using the Approaches to Teaching Inventory 22 (ATI; Trigwell and Prosser 2004, Trigwell et al. 2005) and surveys that we designed to document the PDs' knowledge and experience with active-learning pedagogy and teaching strategies. The ATI measures qualitative variation in two key dimensions of teaching; specifically, conceptual-change/student-focused (CCSF) and information-transmission/teacher-focused (ITTF).

Classroom teaching practice was assessed by experts who used the Reformed Teaching Observation Protocol (RTOP). The RTOP is a validated observational instrument designed to measure the degree to which classroom instruction uses "reformed teaching" as defined by Sawada et al. (2002). The RTOP focuses on the nature of student learning and student-student and student-faculty interactions and is aligned with the theoretical underpinnings of constructivist literature about teaching and learning (Piburn et al. 2000, MacIsaac and Falconer 2002, Sawada et al. 2002, Marshall et al. 2011). It is a highly reliable instrument in terms of item reliability and inter-rater reliability across institutions and instructors (Marshall et al. 2011, Amrein-Beardsley and Osborn Popp 2012). Each video recording was rated by at least two experts and all experts were calibrated with each other in the use of the RTOP. The average total scores for each video recording were assigned to the appropriate RTOP category (Table 1), with categories I-II indicating a teacher-centered class session and the remaining categories representing increasingly learner-centered classes.

For comparison purposes we also obtained teaching videos from 22 pairs of FIRST and non-FIRST biology faculty. Specifically, FIRST graduates were paired with a non-program colleague who was also a junior faculty member at their home institution. Members of a pair taught courses that were similar in topic, class size, and level. Members of each pair provided teaching videos that were then rated by experts using the RTOP and completed surveys about their use of inquiry-based teaching practices.

Research Question 2: What PD and course characteristics were most associated with effective implementation of learner-centered, inquiry-based teaching practices? We determined the extent to which an individual course taught by a PD was learner-centered and inquiry-based by the average RTOP score for that course. We used multiple regression analysis to determine predictive models for RTOP score. The model with the smallest Akaike's Information Criterion was deemed the best model. Stepwise regression was used to obtain partial r^2 values for each variable in the final model. All analyses were conducted using SAS version 9.3, release TS1M2 (SAS Institute Inc., Cary, North Carolina, USA). Only data from PDs who taught an entire course were used. For PDs who taught more than one entire course we selected one course at random to include in the analysis (n = 101 courses).

Table 1. Scoring categories of the Reformed Teaching Observation Protocol (Sawada 2002).

RTOP Category	Typical RTOP Score	Type of Teaching
I	0 – 30	Straight Lecture
II	31 – 45	Lecture with some demonstration and minor student participation
III	46 – 60	Significant student engagement with some minds-on as well as hands-on involvement
IV	61 – 75	Active student participation in the critique as well as the carrying out of experiments
V	76 +	Active student involvement in open-ended inquiry resulting in alternative hypotheses, several explanations, and critical reflection.

III. Analysis and Findings

In response to our first question, four lines of evidence indicated that the professional development program was highly effective. First, the PDs reported significant gains in theoretical knowledge and first-hand experience in all 11 areas of pedagogy and teaching practice that were surveyed (Fig. 1, paired t-tests, $P < 0.05$). The greatest gains were in experience with cooperative/collaborative learning and case studies.

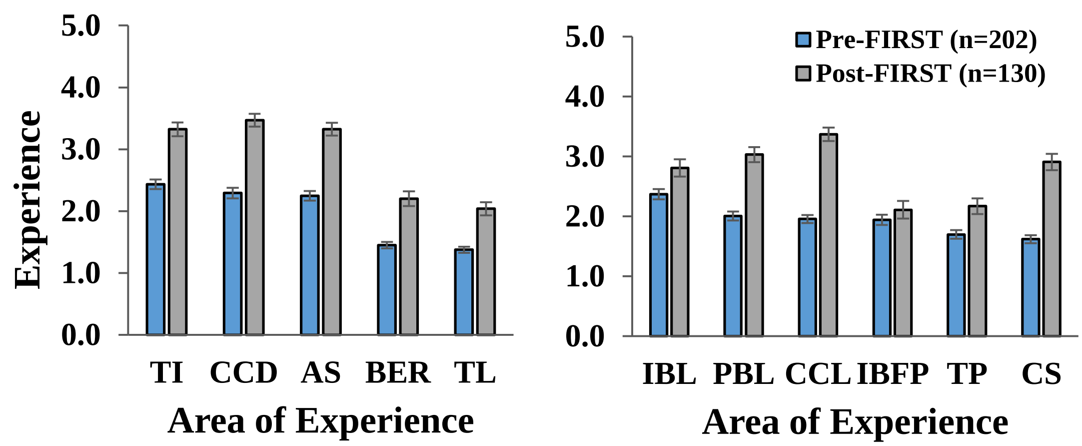

Figure 1. FIRST participants reported gains in first-hand experience with different dimensions of active learning pedagogy (left panel: TI = technology instruction, CCD = course/curriculum development, AS = assessment, BER = biology education reform, TL = theories of learning) and strategies (right panel: IBL = inquiry-based laboratories, PBL = problem–based learning, CCL = cooperative/collaborative learning, IBFP = inquiry-based field projects, TP = teaching portfolios, CS = case studies). All responses were based on a five-point Likert-type scale with 5 being the highest rating and 1 the lowest rating. Error bars represent the standard error.

Second, PD responses to the ATI showed strong support for frequent use of practices consistent with a CCSF approach to learning, combined with significant but less strong agreement with use of ITTF practices. On average, the PDs reported significantly higher ratings on the CCSF scale (mean = 3.87 ± 0.04 on a 5-pt Likert scale) of the ATI, compared with the ITTF scale (mean = 3.28 ± 0.04), when teaching a full course (n = 190 courses; Wilcoxon signed rank test, P < 0.0001).

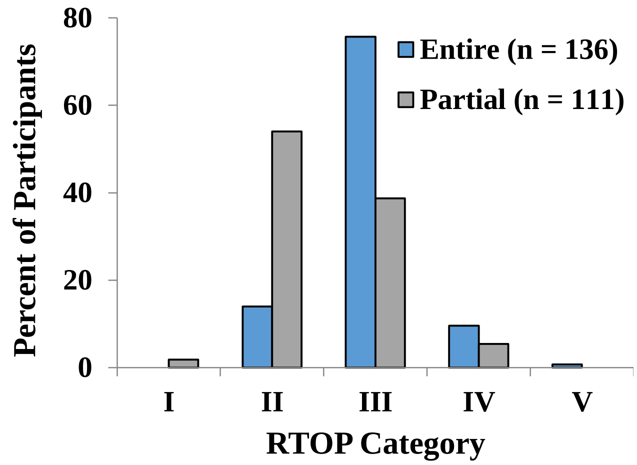

Figure 2. Distribution of total RTOP scores for postdocs that taught an entire or partial course during their participation in FIRST. RTOP categories I-II are teacher-centered, categories III-V are learner-centered.

Third, the majority (> 85%) of PDs taught using significant engagement of students, with students participating in critical thinking about science, as determined by RTOP scores from teaching videos recorded during project participation (Fig. 2). The PDs who taught part of a course rather than an entire course had significantly lower RTOP scores, on average (Figure 2). Course level and enrollment had no significant effect on RTOP score (regression analysis, $F_{2, 146} = 1.51$, $P > 0.05$).

Fourth, self-report data and external reviewers indicated that FIRST participants used more learner-centered approaches to teaching compared with their matched non-program colleague. Specifically, FIRST faculty reported greater frequency of use of student discussions and other small group activities compared with their non-FIRST faculty partner (paired t-test, one-sided P = 0.017 and P = 0.016, respectively). Likewise, expert review of classroom teaching via videos confirmed that FIRST IV graduates taught using learner-centered, inquiry-based approaches to a greater extent than their non-project colleague (Fig. 3). Linear regression analysis with instructor gender and class enrollment as covariates, showed that all else being equal a faculty member who completed the FIRST program is predicted to have an ROTP score approximately one category higher (Table 1) than without FIRST training (Table 2).

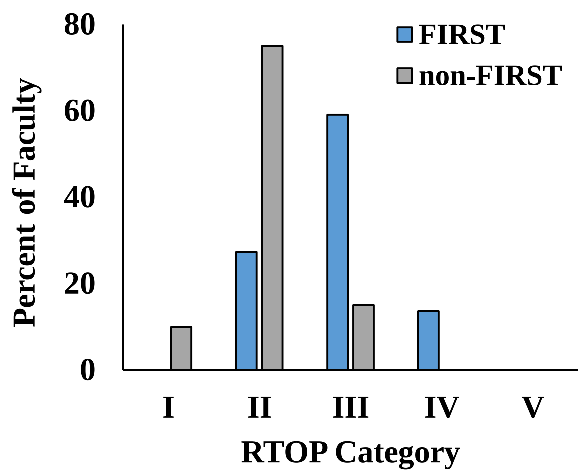

Figure 3. Distribution of total RTOP scores for FIRST graduates (n=22) and non-FIRST faculty (n=20). RTOP categories I-II are teacher-centered, categories III-V are learner-centered.

Table 2. Estimated regression coefficients where treatment is whether or not the faculty member was a FIRST IV graduate and gender and the number of students enrolled in a course are control variables.

Coefficient	**Estimate**	**SE**	***Pr* > |*t*|[a]**
Intercept	39.80	3.10	< 0.0001
Gender	1.53	2.93	0.61
Enrollment	-0.06	0.03	0.06
Treatment	13.72	2.70	<0.0001

[a]significance levels from a 2-sided t-test

The project graduate had a higher RTOP score than the non-project faculty person for 89% of the pairs studied ($X^2 = 15.06$, $P < 0.001$). For 80% of the pairs the RTOP scores for the FIRST IV participants were at least one entire RTOP teaching category higher compared with their non-program partner ($X^2 = 13.06$, $P < 0.001$).

For our second research question we explored PD and course characteristics to determine which were most associated with effective implementation of learner-centered, inquiry-based teaching practices (i.e., RTOP score). We used four sources of self-report data to obtain potential predictors of RTOP score. First were scores for the two subscales (CCSF and ITTF) of the ATI, which indicated the respondent's support for the two teaching strategies. Second was the total score on the Teaching Goal Inventory (Angelo and Cross 1993) that provided a self-assessment of each PD's instructional goals at the beginning of their participation in FIRST. Third was the Experience of Teaching Questionnaire (Trigwell, pers. comm.) that describes the respondent's perceptions of five variables that could affect their teaching experience; i.e., class size, heterogeneity of their students, respondent's control over the course design and implementation, the department's commitment to student learning, and the respondent's workload. Fourth were background and annual surveys that we designed to obtain objective and self-report data about the PDs and their teaching background and perceptions. From the four data sources we had an initial pool of 29 variables that were grouped subjectively into three categories: background/demographics, beliefs about teaching, and course information (Table 3). Twenty four of the 29 variables were retained as potentially related with RTOP score based on a partial least squares analysis. Independence of the 24 variables was confirmed using correlation analysis ($r < 0.7$).

Sixty percent of the teaching practice (i.e., RTOP score) of PDs was explained by the best model which used 12 of the 24 demographic and teaching-related regressor variables (Table 3). Seventy percent of the variation explained by the model was attributable to just five variables: 1) negative support for use of ITTF teaching strategies, 2) positive support for CCSF teaching strategies, 3) a negative perception of high heterogeneity of students (large differences in student talent, English skills, preparedness, etc.) in a course, 4) gender of the PD, and 5) whether the PD had completed one or two years of FIRST training. Lack of support for ITTF approaches to teaching was by far the most influential variable in the model (Table 3). All else being equal, a female PD would be expected to have a significantly higher RTOP score compared with a male PD; and a PD with two years of training would have a higher score than one with only a year of training. These differences in RTOP scores are similar to those of Budd et al. (2013).

Table 3. Potential predictor variables for total RTOP score that were included in a multiple regression analysis. Model coefficients are provided for those variables that were included in the final best model. Partial r^2 values were obtained from stepwise regression analysis.

Predictor Variable	Model Coefficient	Partial r^2	Data Source
BACKGROUND/ DEMOGRAPHICS			
Gender (female > male)	5.2	0.044	Background Survey
Years of FIRST (2 > 1)	3.79	0.033	Annual FIRST Survey
Experience w/ active inquiry teaching practices at end of year 1	-0.12		Annual FIRST Survey
• Knowledge of active inquiry teaching practices • % of appointment dedicated to teaching • FIRST cohort	NS		Background and Annual Surveys
BELIEFS			
Conceptual-change, Student-focused approach	5.03	0.078	Approaches to Teaching Inventory[a]
Information-transfer, Teacher-focused approach	-3.78	0.162	Approaches to Teaching Inventory
Heterogeneity of Student Characteristics	-3.47	0.052	Experience of Teaching Questionnaire[b]
Department's commitment to undergraduate education at beginning of FIRST	-0.52	0.036	Background Survey
Teaching goals at beginning of FIRST	0.44	0.021	Teaching Goals Inventory[c]
Challenges to using active inquiry at end of year 1	-0.27	0.025	Annual FIRST Survey
Challenges to using active inquiry at beginning of FIRST	0.24	0.014	Background Survey
• Self-efficacy • Department commitment to student learning • Class size • Teacher Workload	NS		Self-efficacy Questionnaire[d] Experience of Teaching Questionnaire[b]

COURSE INFORMATION			
Teacher Control of Course Content and Approach	2.18	0.019	Teaching Environment Questionnaire
Course level (100 - 400)	0.02	0.037	
• Majors or non-majors • Enrollment			Course information

[a] Trigwell et al. 2005
[b] Trigwell, pers.comm.
[c] Angelo and Cross 1993
[d] Lindblom-Ylänne et al. 2006

IV. Contribution

We provide strong evidence in support of a professional development program for biologists that results in educators who truly implement learner-centered, inquiry-based teaching in their courses. Furthermore, our results provide data in support of effective change strategies (Henderson et al. 2011). Graduates of FIRST IV reported a high level of belief in CCSF practices and expert reviews of videos of classroom sessions documented high levels of student engagement that differed markedly from the teaching used by non-FIRST faculty. We do not know of any other professional development program with similarly-documented positive outcomes.

Our model of variables that predicted the extent of learner-centered teaching, as measured by the RTOP, provides insights into factors that may be important elements when working towards change in science teaching. The most important variables were related to beliefs of the PDs about teaching strategies. Our result emphasizes that the way instructors approach their teaching is influenced profoundly by their beliefs and conceptions about teaching (Lindblom-Ylanne et al. 2006, Postareff et al. 2007). Interestingly, variables about the courses themselves, such as course enrollment, majors or non-majors course, etc., had either minimal influence on the model or were not included in the final model at all. The predictive model presented here was markedly better at explaining RTOP score compared with a similar effort in which the final regression model only explained 19% of the variation in total RTOP score (Ebert-May et al. 2011). We attribute the increase in predictive ability to our inclusion of data on participants’ beliefs about their approach to teaching and their perceptions about factors that can influence the design and implementation of classroom teaching.

V. Implications

Our contributions are of major importance to the national effort to stimulate change in teaching practices in science education to enhance student learning. Key characteristics of our program, specifically a focus on future faculty, mentoring, and long-term, in-depth engagement in learner-centered teaching and course design, are transferable to training faculty in different science disciplines. The key components also provide direction for the development and funding of future professional development programs.

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