Investigating the linkage between professional development and mathematics instructors' adoption of IBL teaching practices

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Inquiry Based Learning (IBL) professional development workshops are designed to increase participants' capacity to teach using IBL methods. This study used a sample of 312 participants from workshops held in 2010-2018 to examine the relationship between professional development participation, IBL capacity, and use of IBL teaching practices. We found that instructors' IBL capacity, meaning the beliefs, knowledge and skills that prepare them to use IBL, and use of IBL teaching practices increased after participating in professional development. Using the Theory of Planned Behavior as a conceptual framework, we used a structural equation model to explain the effects of workshop participation and other factors on the use of IBL teaching practices. Findings indicated that workshop participation, collegial support, prior IBL experience, class size, and course coordination influenced workshop participants' use of IBL teaching practices. These findings support the use of well-designed, intensive professional development as a means to change teaching practices.

Keywords: Inquiry-based learning, Professional development, Workshops, Teaching

Introduction

Student-centered, research-based instructional strategies (RBIS) such as inquiry based learning (IBL) improve learning and persistence in US undergraduate STEM education (Freeman et al., 2014; Ruiz-Primo, 2011). Recent studies in various STEM disciplines show that approximately 20% of instructors use these methods extensively (Stains et al., 2018; Eagan, 2016). Thus, most students do not experience active learning methods regularly: instructor adoption is a primary constraint to more widespread use of RBIS. There is expert consensus that professional development is one of the most influential factors in facilitating the use of RBIS in undergraduate STEM teaching (Khatri et al., 2013; Laursen et al., 2019). Only a few studies have linked teaching-focused professional development (PD) to teaching behavior of college instructors, and they are in science disciplines, not mathematics (Benabentos et al., 2020; Chasteen & Chattergoon, 2020; Manduca et al., 2017; Viskupic et al., 2019). The purpose of this study is to contribute to this limited literature by investigating the linkage between professional development and mathematics instructors' adoption of IBL teaching practices.

Theoretical Framework

The theory of planned behavior (Ajzen, 1991) has been applied to professional development (Patterson, 2001), teaching practice (Lee et al., 2010; Sadaf & Johnson, 2017), and in at least one study, both professional development and teaching practice (Chasteen & Chattergoon, 2020). In this study, we apply this theory to explain how participation in an intensive professional development workshop influences instructors' use of IBL methods.

The theory of planned behavior assumes that behavior is "planned" or rational and proposes that behavioral intention determine actual behavior (Figure 1). Behavioral intent is influenced by three components: attitude, subjective norm, and perceived behavioral control. Attitude refers to a person's favorable or unfavorable evaluation of the behavior of interest. Subjective norm refers to perceptions about whether their peers approve or disapprove of a behavior. Perceived behavioral control refers to an individual's perception that they have the ability to perform the behavior and that the behavior is under their control. Thus, it too moderates the relationship between behavior intention and behavior: according to the theory, strong perceived behavioral control is required for behavioral *intention* to manifest in *actual* behavior. The theory can be adapted to include other factors (e.g. demographics) that influence any of the core components.

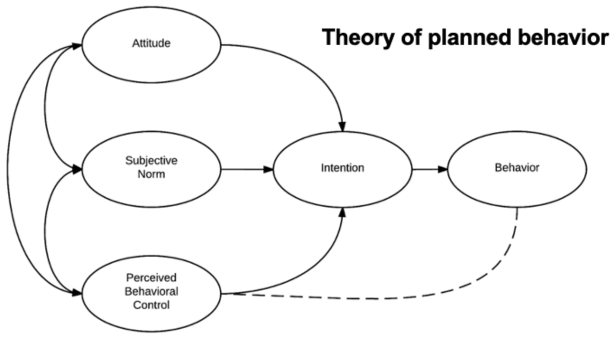

Figure 1. Theory of Planned Behavior, after Ajzen 1991

In applying the theory to this study, the behavior of interest is instructors' use of IBL teaching practices. This behavior is affected by their intent to use IBL teaching methods and their ability (e.g., knowledge and skill) to use IBL teaching methods. Instructors' intent to implement is affected by their attitude about IBL, their perceptions of peer support (subjective norm) and their IBL knowledge and skills (perceived behavioral control). While not portrayed in Figure 1, the theory accommodates other factors outside of the core model. Here we acknowledge that factors such as individual characteristics and the context of instructors' teaching may influence the degree to which they plan to implement or actually do implement IBL teaching practices.

Practical context for the study: IBL Intensive Workshops

Since 2010, 22 intensive workshops on IBL have served about 700 college mathematics instructors. The workshops offered instructors knowledge and skills to implement IBL in their own classrooms and sought to bolster their confidence and support their IBL decision-making. Four-day workshops were held in the summer at locations around the US.

While the workshop hosts and leaders varied over time, broad features of the workshops were consistent, including use of active and collaborative learning methods for teaching instructors about IBL. The current workshop model is grounded in research and practical experience with PD and incorporates video lesson study, educational research, IBL facilitation skills, and personal work time (Yoshinobu et al., 2021). Workshops accommodate instructors' diverse teaching settings because they do not promote a particular curriculum or classroom practice, but rather focus on pedagogy. The workshops have been described in some detail by Kogan and Laursen (2012); Hayward and Laursen (2014); Hayward and Laursen (2016); and Yoshinobu et al. (2021).

Research questions

The purpose of this research was to investigate the linkage between professional development and mathematics instructors' adoption of IBL teaching practices. To this end, this study addresses the following research questions:

1. To what degree do mathematics instructors' IBL attitudes, knowledge, and skill change after professional development?
2. How do teaching practices change 18 months after professional development?
3. What is the relationship between teaching practice, professional development, and other factors (e.g., individual, institutional, and teaching contexts)?

Methods

Data collection and sample

Workshop participants completed a pre-workshop survey about one month before their workshop, a post-workshop survey immediately after, and a follow-up survey about 18 months later. Analyses were limited to participants in the 2010-2018 workshop cohorts (n = 517) who completed all three surveys (n = 312), yielding a 60% completion rate. About half (49%) had IBL teaching experience. The sample included instructors from a range of institution types (Ph.D-granting 26%, Master's 24%, Four year 44%, 2 year 6%), and half of the participants were early-career instructors (50% with five years or less teaching experience). Over half (56%) were women (56%), higher than the general representation of women in mathematics (NSF, 2015).

Measures

Surveys included well-established measures (Hayward & Laursen, 2014; Hayward et al., 2016; Kogan & Laursen; 2012) from several categories related to our theoretical framework (Table 1). For constructs with more than one survey item, we calculated a measure of internal consistency. All constructs showed acceptable internal consistency (Chronbach's $\alpha \geq 0.70$).

Table 1.
Map of theoretical constructs, survey measures, categories, scales, survey administrations

Theoretical construct	Variable categories	Survey item	Scale	Survey admin (Chronbach's α)
Attitude	IBL capacity (belief)	Extent you believe inquiry strategies are effective learning method	1 = Don't know 2= Not very effective 3= Somewhat effective 4 = Highly effective	Pre Post Follow-up (single item)
Subjective norm	Departmental collegial support for IBL	Support from dept. colleagues to use IBL in teaching Support from dept head or chair	1 = Not at all supportive, 2= Mostly not supportive 3= Mixed or moderate support 4 = Mostly supportive	Follow-up (0.81)
Perceived behavioral control	IBL capacity (knowledge, skills)	How would you rank your current level of knowledge/skill in inquiry-based teaching?	1=None, 2=A little, 3=Some, 4=A lot	Pre (0.81), Post (0.71, Follow-up (0.72)

Behavioral intent	Intent to implement IBL	How likely implement in next academic year	1 = Not at all likely 2 = Somewhat unlikely 3 = Somewhat likely 4 = Rather likely 5 = Definitely	Post (single item)
Behavior	IBL intensity (core IBL teaching methods, -see Hayward et al., 2016)	Frequency of use of core IBL methods = student group work + student presentation + class discussion - lecture – instructor solving problems	1= Never, 2= Once or twice a term, 3 = About once a month, 4= About twice a month, 5= Weekly, 6= More than once a week, 7= Every class	Pre (0.75), Follow-up (0.70)
Other factors outside of the model	Individual characteristics	Career stage, teaching experience Gender, ethnicity, & race Prior IBL teaching experience		Pre, Follow-up
	Institutional characteristics	Institution type (highest math degree) Minority-serving institution		Follow-up
	Teaching contexts	Class size, course coordination, student majors, student level		Follow-up

Data analysis

RQ1 was answered by conducting a one-way ANOVA with repeated measures to check for differences in three IBL capacity measures over three time points. RQ2 was answered by using a paired samples t-test to test for differences in pre-workshop and follow-up IBL scores. RQ3 was answered by creating a structural equation model (SEM) based on the theory of planned behavior, to describe the relationships between corresponding theoretical components.

To maximize model parsimony, only three additional variables (prior IBL teaching experience, small class size, and course coordination) were included in the SEM used to answer RQ3. These variables were identified by conducting a series of preliminary analyses (e.g. ANOVA, regression) that checked for differences in three outcome measures (IBL capacity, intent to implement IBL, and IBL intensity) by all individual, institutional, and teaching context factors. These analyses yielded few statistically significant differences when controlling for all other factors; variables that did yield such differences were included in the SEM.

Results

First, we describe findings related to RQ1, addressing the degree to which IBL attitude, knowledge, and skill change after professional development. A one-way ANOVA with repeated measures was conducted to test for differences in measures of IBL capacity among three time points (pre, post, follow-up). We found statistically significant increases in all capacity measures from pre to post workshop (Table 2). Effect sizes (η^2) indicate the largest increases were in IBL knowledge and skill, with a smaller positive change in attitude about IBL effectiveness. From post workshop to 18-month follow-up, we found no difference in knowledge, a statistically significant decrease in attitude, and a statistically significant increase in skill. However, the small differences in attitude and skill were negligible considering the corresponding survey scales (see Table 1).

Table 2
Changes in IBL capacity: ANOVA Results for differences in mean scores by time point (N = 305)

	Pre-workshop		Post-workshop		18-month Follow-up		Omnibus Statistics		
IBL Capacity	*M*	*SD*	*M*	*SD*	*M*	*SD*	*F* (df = 2, 304)	*p*	η^2
Attitude	**3.36**	0.91	**3.84**	0.42	**3.67**	0.52	60.21	<0.001	0.17
Knowledge	**2.46**	0.70	**3.27**#	0.61	**3.20**#	0.60	248.06	<0.001	0.45
Skill	**1.95**	0.74	**2.53**	0.66	**2.77**	0.62	234.70	<0.001	0.44

Note. *M* = mean, *SD* = standard deviation, *F* =*F* statistic, p = probability, *df* = degree of freedom, η^2 = partial eta squared (effect size). Means within each row differ at p < 0.001 except for those marked with #.

To answer RQ2, we used a paired samples t-test ($n = 231$) to test for differences between pre-workshop and follow-up IBL intensity scores. Follow-up scores ($M = 6.78$, $SD = 4.67$) were significantly higher ($t(230) = 14.15$, $p < 0.001$), than pre-workshop scores ($M = 0.89$, $SD = 5.43$). A large effect size (*Cohen's d* = 0.93) indicated a strong meaningful change in IBL teaching intensity from pre-workshop to follow-up, as shown in Figure 2.

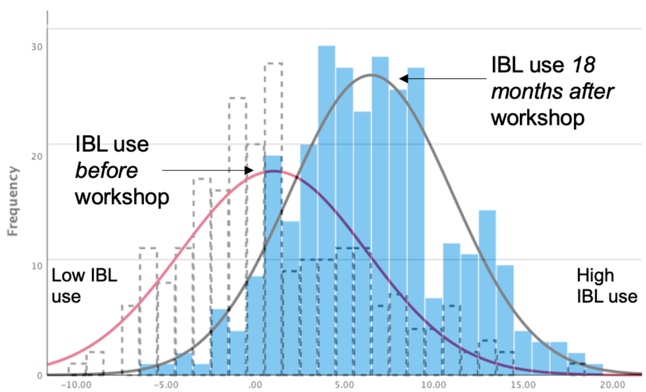

Figure 2. Change in IBL teaching practice: Distributions of IBL intensity scores before workshop and at follow-up

We used structural equation modeling to answer RQ3. Two fit indices (CFI and RMSEA) were used to assess model fit. CFI values range from 0-1, where values ≥ 0.95 are considered well-fitting (Hu & Bentler, 1999). RMSEA values ≤ 0.05 indicate close fit (Browne & Cudeck, 1993). The SEM (Figure 3) showed excellent model fit (*CFI* = 0.99, *RMSEA* = 0.01) and explained a moderate amount of variability ($r^2 = 0.21$) in IBL intensity, the intended behavior.

We see positive, statistically significant relationships between all specified components in the model. Of the four variables theorized to influence intent to implement IBL, two had a moderate effect, while two others had smaller effects. For actual implementation, IBL knowledge and skill had the strongest association, and three other variables were moderately associated.

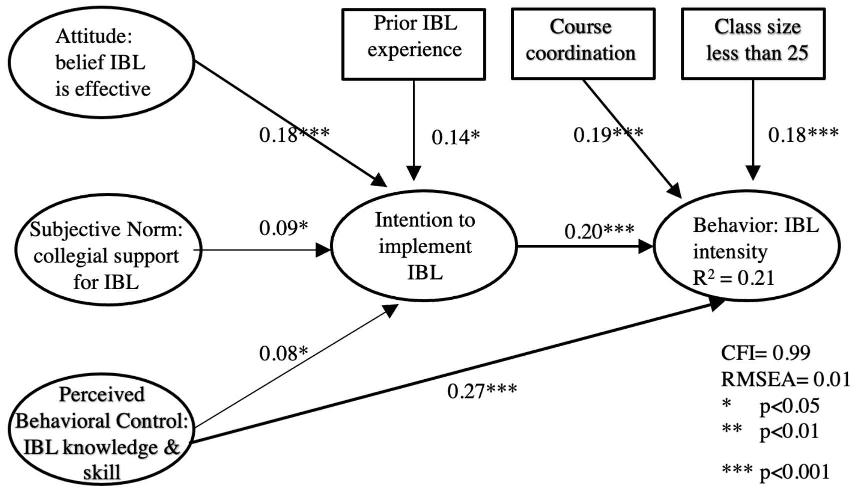

Figure 3. Structural equation model of the theory of planned behavior with standardized regression coefficients.

Discussion

The findings show strong linkages between professional development and use of IBL teaching practices. First, findings for RQ1 showed that participants' IBL capacity increased after participating in professional development. On average, faculty came to workshops with a strong belief about the effectiveness of IBL and thus had little opportunity for growth in this measure of capacity. Their initial strong positive attitude toward IBL did show a significant increase after attending workshops that persisted for 18 months after the workshop, indicating the workshop had a lasting effect. Larger gains in knowledge and skill from pre- to post-workshop were also sustained 18 months after the workshop. Participants reported greater gains in knowledge than skills: knowledge is gained quickly in a workshop, while skills develop over time with practice.

Strengthened positive attitudes, knowledge and skills may stem from workshops' emphasis on educational research about IBL teaching and on design principles and practical ideas for IBL courses. Research in physics has likewise shown that PD can both strengthen attitudes and improve knowledge of RBIS after workshop participation (Chasteen & Chattergoon, 2020).

Related to RQ2, we found that 18 months after taking part in PD, instructors' teaching became more IBL-intensive and less instructor-focused. The large effect size showed a substantial shift in IBL teaching intensity: most were not just dabbling with IBL practices but making substantial changes. Prior work in physics is mixed: some results show that many instructors abandon RBIS soon after initial adoption (Dancy & Henderson, 2010; Henderson & Dancy, 2009), and other work shows high initial adoption (Chasteen & Chattergoon, 2020). We suggest that IBL workshops promote implementation by providing time for instructors to plan their course and adapt methods to their own context (Hayward & Laursen, 2016).

Findings related to RQ3 were consistent with our theoretical framework. Model fit indices show that our data fit the model well, and observed statistically significant positive relationships demonstrate consistency with theorized relationships. First, the model specified four factors related to intent to implement IBL. The modeled relationships are all consistent with theory and are shown here in order from strongest to least strong factor according to our SEM:

- IBL attitude: As instructors' pro-IBL attitudes strengthened, intent to implement IBL also strengthened. (model coefficient 0.18)

- Prior IBL experience: Instructors with prior IBL experience had stronger intent to implement IBL than those without (model coefficient 0.14). Prior IBL experience has been identified as a factor that aided IBL implementation (Laursen et al., 2019).
- Perceived departmental support: Instructors reporting supportive peers were more likely to intend to use IBL, compared to those with less supportive peers (model coefficient 0.09). This finding corroborates prior research (McConnell et al., 2020).
- IBL knowledge and skill: Instructors with high knowledge and skill were more likely to intend to implement IBL than were instructors with less knowledge and skill (model coefficient 0.08).

The model specified four factors related to IBL intensity. The modeled relationships are all consistent with theory and are ordered here from strongest to least strong, according to our SEM:

- IBL knowledge and skill: On average, instructors with high knowledge and skill implemented IBL more intensively than did instructors with less knowledge and skill. (model coefficient 0.27)
- Intent to implement IBL: Instructors with high intent tend to use IBL more intensively than those with weaker intent. (model coefficient 0.20)
- Coordinated courses: Instructors teaching coordinated courses were more IBL-intensive than those whose courses were not coordinated, consistent with prior work linking course coordination to use of active learning strategies (model coefficient 0.19) (Bazett & Clough, 2020; Rasmussen et al., 2014).
- Small class size: Instructors who applied IBL in smaller classes were more likely to use IBL more intensively than those who taught larger classes (model coefficient 0.18). Some IBL teaching practices (e.g., student presentations) are harder to use in larger classes, especially for new users. Class size has been identified as one of the top factors making IBL implementation more difficult for new users (Laursen et al., 2019). Importantly, our finding reflects initial implementation in the first academic year after the workshop, and does not speak to whether small classes are important for long-term use of IBL. We know of many experienced instructors who use IBL effectively in large classrooms.

Connecting findings from RQ1 and RQ2, it appears that workshops increase IBL capacity, which in turn increases instructors' use of IBL teaching practices. Findings about RQ3 support this conclusion, as IBL knowledge and skill had the strongest association with IBL teaching intensity in this model. A positive attitude about IBL teaching, support by department colleagues, and prior IBL experience were important in supporting intentions to use IBL teaching, but skills and knowledge enabled instructors to actually implement IBL. Teaching contexts do matter: coordinated courses and class sizes can influence how intensively IBL is implemented.

These findings point to several practical implications. Investments should focus on intensive PD to strengthen instructors' attitudes and their knowledge and skill to enact RBIS. Targeted efforts to inform and train department leaders, faculty, and course coordinators to create supportive environments could also hasten uptake of IBL and other RBIS. Supporting initial implementation with small class sizes or team efforts could ultimately offer more students more research-aligned teaching practices, as instructors develop skills in more forgiving circumstances and then learn to adapt their practices to different teaching contexts.

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