Implementation of IBL in Undergraduate Calculus Classes

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We report the results of a survey of calculus instructors from colleges and universities across the US related to their reported awareness and usage of Inquiry Based Learning, instructional practices, and beliefs about teaching and learning. Cluster analysis of the data revealed three distinct types of self-identified IBL-users based on the proportion of in-class time students spent in different activities, including a large number of instructors who lecture for the majority of class time. The teaching practices of that sub-group did not differ significantly from those of the group of instructors who reported no knowledge of IBL. Variation in level of agreement with positive statements about lecture shows some association with in-class instructional practice; all four groups indicate strong agreement with statements that inquiry practices support learning.

Keywords: Instructional practices, Calculus, STEM, Individual Characteristics

Introduction

Inquiry forms of instruction have been part of broader educational reforms going back at least to the work of John Dewey (Artigue & Blomhøj, 2013) and one manifestation of this in mathematics education has been inquiry-based learning (IBL). Broadly, the pedagogical approach called IBL has been practically defined as having students engage with each other and in actively reinventing mathematics through a carefully constructed sequence of high-level tasks while an instructor acts as a 'guide on the side' to facilitate students' activity and discussions towards the curricular content agenda (Artigue & Blomhøj, 2013; Ernst et al., 2017; Hayward et al., 2016; Laursen & Rasmussen, 2019; Rasmussen & Kwon, 2007). The IBL community typically offers guidelines and principles to instructors; with less emphasis prescribed, specific pedagogical choices for implementing IBL. While not narrowly defined, IBL is usually associated with student-centred instruction and activities such as working in small groups, presentations, and whole-class discussions and decreased use of instructor-activities such as lecturing and solving problems (Hayward et al., 2016; Kogan & Laursen 2014; Laursen et al. 2014). The variety in implementations of IBL lends to be conceived of a spectrum of related activities, as opposed to a ridged instructional format.

Given how broadly IBL is defined and how similar the tenets of IBL are to other active learning approaches more generally (Ernst et al. 2017; Rasmussen & Kwon, 2007; Rasmussen, Marrongelle, Kwon, & Hodge, 2017; Walczyk & Ramsey, 2003), the way in which IBL is implemented by individual instructors may be largely dependent on widely varying instructor beliefs. While IBL is fairly well-known and promoted among mathematicians (see results in Apkarian et al., 2019), there are open questions about whether IBL is being implemented in ways that are consistent with the tenets of IBL, something other researchers have questioned as well (Stains & Vickery, 2016). We do not know if IBL implementation translates into a clearly distinct set of instructional practices within active learning, or the extent to which IBL implementations differ from teacher-centred instructional approaches. Thus, the goal of our paper is to examine whether self-identified IBL implementors have a clearly definable set of instructional practices and attitudes, and the extent to which they differ from those who have never heard of IBL. In this paper we address the following research questions:

1. What is the range of instructional practices among instructors of undergraduate calculus courses who report using IBL in their classes, and how does this compare to the practices of those who have no knowledge of IBL?
2. What attitudes toward teaching and learning are associated with different instructional profiles among self-identified IBL users, and how does that compare to those who have no knowledge of IBL?

Literature Review

Prior research has tracked the evolution of IBL as it has become a more formalized, yet broadly conceptualized, pedagogical approach (Ernst et al. 2017; Haberler et al., 2018; Laursen & Rasmussen, 2019; Rasmussen & Kwon, 2007; Rasmussen et al., 2017). Earlier work identified one, then two, then three, and now four guiding principles which are outlined on the *Academy of Inquiry Based Learning* website (inquirybasedlearning.org). Those principles, reviewed by Lauren and Rasmussen (2019) as Inquiry Based Mathematics Education (IBME) were synthesized as 1) deep student engagement in rich mathematics, 2) student collaboration with peers and instructors, 3) instructor inquiry into student reasoning, and 4) instructor attention to equity. In terms of the principle of deep student engagement in rich mathematics, students are to make significant contributions to the curriculum progression and math concept development. Students may not be provided answers or methods to follow ahead of time but instead have to wrestle with ideas before making conclusions; the goal of the instructor is to get the students work on activities that are novel and challenging to them. The second principle, collaboration, involves students working in groups, as a class, and or individually in order to learn how to effectively communicate mathematics and deepen their understanding (e.g. individuals going to present a proof for the class to evaluate); the goal of an instructor is to help students engage with other students' thinking and facilitate cross-talk among students). The third principle of IBME, instructor inquiry in students' reasoning, has been operationalized in various ways in prior research but generally involves instructors eliciting student ideas publicly and building on them (Laursen & Rasmussen, 2019; Rasmussen & Kwon, 2007; Rasmussen et al., 2017); the goal of the instructor is to build on and extend student work. Earlier work by Rasmussen and Kwon (2007) noted that this instructor inquiry helps instructors construct models of student thinking and learning, provides instructors opportunities to gain deeper insight into mathematical ideas by reflecting on student activity, and positions instructors to build off student thinking by posing follow up questions or tasks. The fourth, most recent addition, calls on instructors to attend to classroom dynamics which arise in interactive settings and consciously support an equitable and respectful experience for each student. This principle has been put forward as an aspirational characteristic of IBME (and IBL), not an inherent one (Laursen & Rasmussen, 2019).

Given the broad conceptualization of IBL and how innovative instructional practices are then taken up (Scanlon et al., 2019; Stains & Vickery, 2016), implementation of IBL is likely to vary widely between instructors. One determining factor in how variations in teaching practices arise is instructors' beliefs (Leatham, 2006). Prior research has identified how beliefs, and specifically beliefs about teaching and learning, impact instructional practice (Hoyles, 1992; Leatham, 2007; Philipp, 2007; Speer, 2008; Sztajn, 2003). We conjecture that while IBL is diffused as an innovative instructional practice, the broad nature of IBL will allow instructors to implement IBL in various ways, which will be partly determined by instructors' individual beliefs and goals.

Methods

Survey Overview and Key Items

This work is part of a larger study about factors impacting the uptake of research-based instructional practices in postsecondary chemistry, mathematics, and physics, which included the development and administration of a web-based survey informed by related research in undergraduate STEM education (e.g., Apkarian et al., 2019; Johnson et al., 2018; Gibbons et al., 2018; Henderson & Dancy, 2009; Lund & Stains, 2015; Walter et al., 2016). The survey is an amalgamation and adaptation of items from validated instruments which gathered information about instructors': general instructional practices (Landrum et al., 2017, Walter et al., 2016); beliefs about teaching, learning, and students (Aragón et al., 2018; Chan & Elliott, 2004; Dweck et al., 1995; Johnson et al., 2018; Meyers et al., 2006; Tollerud, 1990); and departmental climate and culture (Walter et al., 2014). The survey also included a section on demographic questions related to both professional and personal identities and roles (see Apkarian et al., 2020 for additional detail). Survey participants were instructed to consider a particular, recently taught course (in mathematics, a single-variable calculus course) when responding.

In this report we focus on data from a subset of the items related to instructional practice and instructor's beliefs about teaching, learning, and students. Our analysis incorporated two items about instructional practice. The first (Table 1A) asked instructors to report the percentage of in-class time (in a typical week) students spent in four kinds of activity: working individually, working in small groups, participating in whole-class discussions, and listening to the instructor lecture or solve problems. The second (Table 1B) asked instructors to rate their familiarity with IBL[1] on a five-point scale from "I have never heard of this" to "I currently use it in this course to some extent." Seven belief items (Table 1C) were queried using a six-point Likert scale from strongly disagree to strongly agree, with no neutral option.

The survey was distributed electronically in Spring 2019, and 3769 instructors of introductory STEM courses at 851 postsecondary institutions across the U.S responded. Of these, 1349 were instructors of undergraduate single-variable calculus courses; here we report only on responses from the 967 who responded to all of our target items. We further reduced the dataset to include only 366 respondents: those we refer to as IBL users (289 instructors who report currently using IBL in their calculus course) and non-IBL (nIBL) instructors (77 instructors who report never having heard of IBL).

Table 1. Survey question, in which participants: (A) selected the percentage of class time spent in each of four activities from drop-down menus of 0, 5, 10, …, 95, 100; (B) selected one of five options describing their level of awareness or experience with IBL; and (C) indicated their level of agreement with seven Likert items. Statements 1-4 are positive statements about lecture; statements 5-7 are statements aligned with an inquiry perspective on learning. These statements were presented to participants as part of a larger set and in a scrambled order.

[**A**] During a typical week, what proportion of time during regular class meetings (i.e., lecture sections) do students spend doing the following? (Answers must total 100.)	[ ] Working individually [ ] Working in small groups [ ] Participating in whole-class discussions [ ] Listening to the instructor lecture or solve problems
[**B**] Please indicate your awareness and (if applicable) usage of … Inquiry-Based Learning (IBL): A broad range of empirically validated teaching methods which emphasize	1. I have never heard of this 2. I know the name, but not much more 3. I know about this, but have never used it in this course

[1] The full survey asked mathematics instructors about 12 distinct RBIS, but for this paper we focus on IBL only.

(a) deeply engaging students and (b) providing students with opportunities to authentically learn by collaborating with their peers	4. I have tried it in this course, but no longer use it 5. I currently use it in this course to some extent
[**C**] To what extent do you agree/disagree with the following statements? *Strongly disagree, disagree, slightly disagree, slightly agree, agree, strongly agree* 1. I think lecture is the best way to teach. 2. Students learn best from lectures, provided they are clear and well- organized. 3. I think lecture is the only way to teach that allows me to cover the necessary content. 4. The major role of a teacher is to transmit knowledge to students. 5. I think students learn better when they struggle with the ideas prior to me explaining the material to them. 6. Making unsuccessful attempts is a natural part of problem-solving. 7. Learning means students have ample opportunities to explore, discuss, and express their ideas.	

Data Analysis

Our goal was to investigate how different or similar were the instructional practices of calculus instructors implementing IBL in their classes. Specifically, we wanted to classify the 289 self-reported IBL-users based on their reported breakdown of how class time is spent (Fig.1). To accomplish this task, cluster analysis was conducted to identify homogeneous groups of participants and the four clustering variables were the instructional practices: working individually (WI); working in small groups (WSG); participating in whole class discussion (WCD); and listening to the instructor lecture or solve problems (LL).

To determine the optimal number of clusters, a combination of hierarchical and non-hierarchical methods was used. Hierarchical cluster analysis using the Centroid Clustering method with Euclidean Distance as a measure of distance revealed that the respondents could be clustered into three distinct groups. To test for robustness, a *k*-means cluster analysis was conducted. The *k*-means cluster profiles were in agreement with those obtained from hierarchical cluster analysis, thus supporting the three-cluster solution. A one-way analysis of variance within the clusters was then performed to examine the difference among the four instructional practices across the three clusters. Tukey's post hoc HSD testing was used to assess pairwise differences in the amount of class time spent in each activity between instructor groups.

The final stage of analysis involved examining individual beliefs about teaching and learning associated with instructors across the three clusters of self-reported IBL-users and those who reported to have no knowledge of IBL (nIBL). Within each cluster, we examined the participants' beliefs around instruction. We compared the means of the participants' responses to seven Likert items (Table 1C) using Tukey's HSD test. Participants responded to the items on a measuring scale of 1 (strongly disagree) to 6 (strongly agree).

Results

Instructional Profiles

The *k*-means cluster analysis of the instructional practices of self-declared IBL users identified three distinct groups of practitioners. Based on their instructional profiles (Fig. 2), we refer to the three clusters of IBL-users as MSG (mostly small group work), MW (mixed ways), and ML (mostly lecture). The MSG group report the highest average of class time spent in small-group work (53%); the MW group do not have a dominant instructional activity; ML is the largest group and report the highest average of class time spent in didactic lecture (62%). For context, we compare these instructional profiles to of those who report never having heard of IBL (nIBL). As shown in Figure 1 and confirmed in Table 2, the nIBL group reports a class time distribution very like that of the ML group (average 65% class time spent in lecture). For each of the four instructional activities, group membership has a statistically significant main effect on the amount of time spent in that activity (see Figure 2 caption).

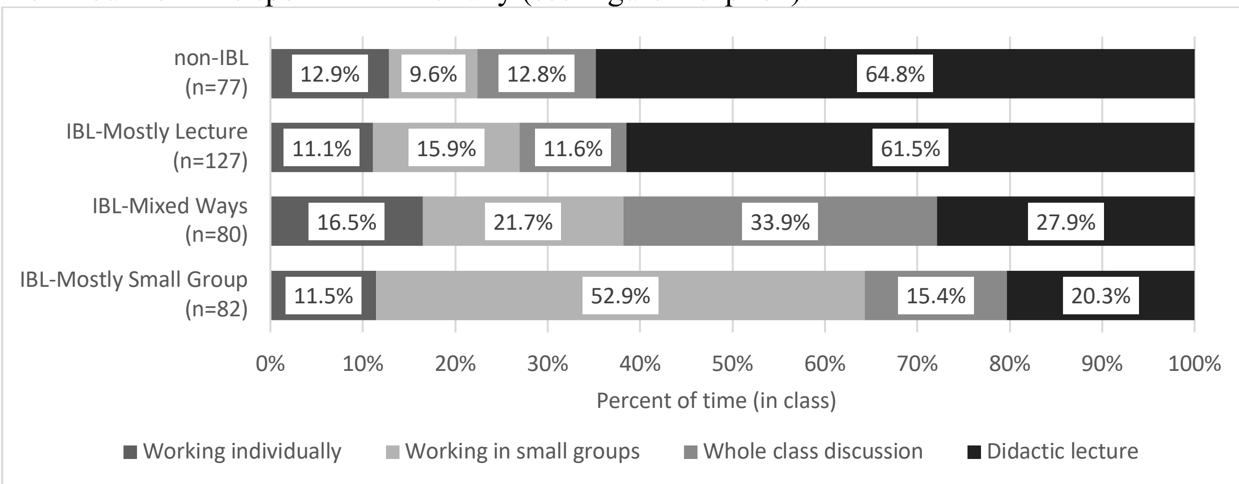

Figure 1. Stacked bar charts of the percentage of class time spent in each of four pedagogical activities. ANOVA indicate group impacts the amount of time students spend in each activity: working individually $F(3,362)=4.07$, $p<0.01$, $\eta^2=0.03$; working in small groups $F(3,362)=231$, $p<0.001$, $\eta^2=0.66$; whole class discussion $F(3,362)=73.32$, $p<0.001$, $\eta^2=0.38$; and didactic lecture $F(3,362)=196.9$, $p<0.001$, $\eta^2=0.62$.

We then compare the instructional practices across these three groups and the non-IBL users using (Table 2). The three types of IBL users varied in their instructional practices and there were significant differences between the groups. ML and nIBL were distinguished only by a medium-sized effect of time spent working in small groups; there are large differences in the amount of time these groups spend in lecture compared to MW and MSG (who differed slightly). Small group work varied the most across groups, and individual work time the least.

Table 2. Results of Tukey HSD post hoc testing at 95% family-wise confidence intervals between instructor groups for each of the four pedagogical activities. Cells show difference of group means.

	MSG-MW	MSG-ML	MSG-nIBL	MW-ML	MW-nIBL	ML-nIBL
Working individually (WI)	-5.0* d=0.5[Med]	*ns*	*ns*	5.4** d=0.6[Med]	*ns*	*ns*
Working in small groups (WSG)	31.2*** d=2.9[Lrg]	37.0*** d=3.2[Lrg]	43.3*** d=3.4[Lrg]	5.8** d=0.5[Med]	12.1*** d=1.0[Lrg]	-6.3** d=0.5[Med]
Participating in whole class discussion (WCD)	-18.6*** d=1.5[Lrg]	*ns*	*ns*	22.4*** d=2.0[Lrg]	21.1*** d=1.5[Lrg]	*ns*
Listening to instructor lecture (LL)	-7.6** d=0.7[Med]	-41.2*** d=3.3[Lrg]	-44.5*** d=2.4[Lrg]	-33.6*** d=2.7[Lrg]	-36.9*** d=2.0[Lrg]	*ns*

*p<0.05, **p<0.01, ***p<0.001; differences which were not statistically significant (ns) are omitted.
Effect sizes calculated for significant differences using Cohen's d: 0.2 < Small < 0.5< Medium < 0.8 < Large.

Attitudes to Teaching and Learning

In terms of individual beliefs about teaching and learning, we calculated the group mean scores for seven items (Figure 2) and conducted a Tukey HSD test (Table 3).

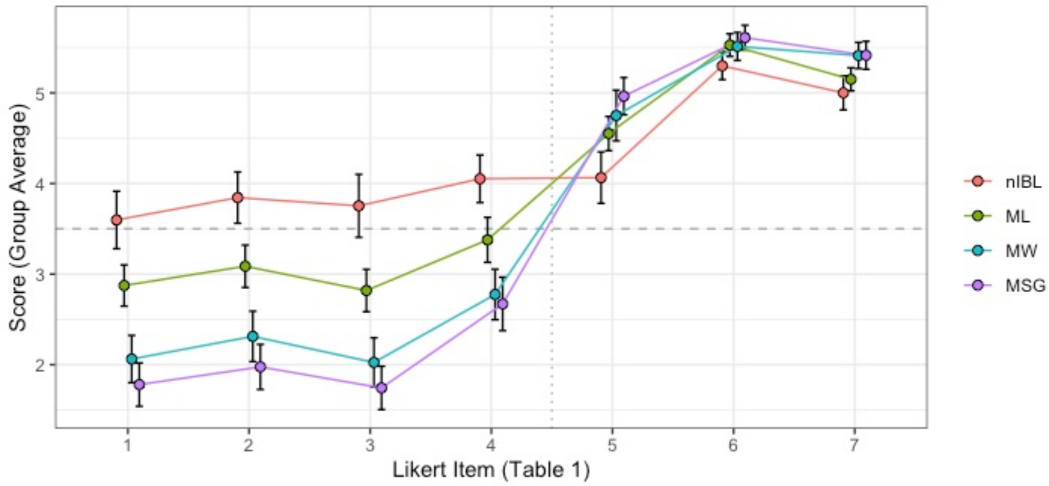

Figure 2. Mean and 95% CI of the mean of each instructional group's responses to each of the seven selected Likert items. A vertical line separates the statements about lecture (1-4) and statements about learning through inquiry.

The MSG and MW groups were indistinguishable in their responses to these Likert items. All four groups indicated agreement with statements that inquiry supports learning, with some variation. The groups differed in their responses to the positive statements about lecture. MSG and MW indicated the strongest disagreement, followed by IBL-users who mostly lecture, and the nIBL group reported mild agreement.

Table 3. Results of Tukey HSD testing (differences of group means) at 95% family-wise confidence intervals.

	MSG – MW	MSG – ML	MSG – nIBL	MW – ML	MW – nIBL	ML – nIBL
1. I think lecture is the best way to teach	*ns*	-1.1*** *d*=0.9[Lrg]	-1.8*** *d*=1.5[Lrg]	-0.8*** *d*=0.7[Med]	-1.5*** *d*=1.2[Lrg]	-0.7*** *d*=0.5[Med]
2. Students learn best from lectures, provided they are clear and well-organized	*ns*	-1.1*** *d*=0.9[LRg]	-1.9*** *d*=1.6[Lrg]	-0.8*** *d*=0.6[Med]	-1.5*** *d*=1.2[Lrg]	-0.8*** *d*=0.6[Med]
3. I think lecture is the only way to teach that allows me to cover the necessary content	*ns*	-1.1*** *d*=0.9[Lrg]	-2.0*** *d*=1.5[Lrg]	-0.8*** *d*=0.6[Med]	-1.7*** *d*=1.3[Lrg]	-0.9*** *d*=0.6[Med]
4. The major role of a teacher is to transmit knowledge to students	*ns*	-0.7*** *d*=0.5[Med]	-1.4*** *d*=1.1[Lrg]	-0.6** *d*=0.5[Sm]	-1.3*** *d*=1.1[Lrg]	-0.7** *d*=0.5[Med]
5. I think students learn better when they struggle with the ideas prior to me explaining the material to them	*ns*	0.4* *d*=0.4[Sm]	0.9*** *d*=0.8[Lrg]	*ns*	0.7*** *d*=0.6[Med]	0.5* *d*=0.4[Sm]
6. Making unsuccessful attempts is a natural part of problem-solving	*ns*	*ns*	0.3* *d*=0.5[Sm]	*ns*	*ns*	*ns*
7. Learning means students have ample opportunities to explore, discuss, and express their ideas	*ns*	*ns*	0.4** *d*=0.5[Med]	*ns*	0.4** *d*=0.6[Med]	*ns*

Adjusted *p<0.05, **p<0.01, ***p<0.001; differences which were not statistically significant (ns) are omitted. Effect sizes calculated using Cohen's d (rounded to one decimal place) 0.2 < Small < 0.5< Medium < 0.8 < Large

Discussion

The primary objective of this report was to characterise self-identified calculus IBL implementors based on proportion of in-class time students spent on four different activities alongside their beliefs about teaching and learning. First, we hoped to gain insights into how different or similar IBL classrooms would be and examine the differences, which we conjectured may exist, between IBL and non-IBL classrooms. Second, we sought to examine to what extent instructors' beliefs about lecture and non-lecture align with their instructional practices.

Addressing our first research question, we found the instructional practices of IBL instructors varied remarkably. Our cluster analysis identified three distinct groups – with significant difference in instructional practice. In one cluster small group work dominated the instructional time; in one cluster class time was pretty evenly distributed between four different instructional practices; and, in one cluster students spent the majority of in-class time listening to the instructor lecture. If we take into account the number of IBL instructors in each of the three clusters we see that a significant portion of these self-identified IBL users, about 43% of them, were sorted into the "mostly lecture" group, where students spent on average 62% of in-class time listening to the instructor lecture. In terms of instructional practice, there was limited variability reported by this "mostly lecture" cluster of IBL implementors and instructors who reportedly have never heard of IBL. Thus, our findings imply that it would be a mistake to assume a consistency between IBL courses or to assume that in IBL classrooms the majority of class time is spent on student-centred activities. Further, we concur with researchers (e.g., Hayward et al., 2016) that future efforts to spread IBL should examine factors that influence implementing IBL and support instructors to incorporate IBL practices in their instruction.

Second, we found statistical alignment across all the IBL clusters (despite instructional differences) with regards to their attitudes toward inquiry learning, but these attitudes were also shared by those with no knowledge of IBL. Thus, acknowledging inquiry as supportive of learning does not appear associated with stated IBL usage or instructional practice. However, attitudes toward lecture do appear to have this association. Self-declared IBL users indicated more disagreement with positive statements about lecture than the nIBL group, and there is a tentative association between agreement with positive statements about lecture and the percentage of class time spent lecturing. The responses of self-identified IBL-users whose classes are dominated by lecture are intriguing, and further analysis is needed to understand how this group describe their understanding of IBL as a pedagogical and/or teaching philosophy, their instructional practices, and how their attitudes and beliefs about teaching and learning drive their practical pedagogical decisions within and outside the classroom. Our findings suggest that beliefs about lecture are more related to pedagogical choices than beliefs about inquiry, and that this is an avenue for further investigation by those seeking to shift instructional practice.

Acknowledgement

This material is based upon work supported by the National Science Foundation under DUE Grant Nos. 1726042, 1726281, 1726126, 1726328, & 1726379. Any opinions, findings, and conclusions or recommendations expressed in this material are those of the authors and do not necessarily reflect the views of the National Science Foundation.

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