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An Analysis of the Fidelity of Implementation of Research-Based Instructional Strategies in the Statics Classroom

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Fidelity of Implementation in the Statics Classroom

Abstract

Many teaching innovations have been developed over the last 20 years, including a number of Research-Based Instructional Strategies (RBIS). However, there is limited research to address how many faculty members are using these strategies, or when they do implement them, whether they are following the theory and steps as intended by the developers. The measure of how well an implemented intervention follows the original is called Fidelity of Implementation. This paper seeks to introduce Fidelity of Implementation to the engineering education community. Using a national survey of 166 statics instructors, we investigated the level of self-reported fidelity of nine RBIS. In this paper, we report overall fidelity values and present in-depth results for 3 specific RBIS: Concept Tests, Collaborative Learning, and Problem-Based Learning. Specifically, we discuss how the use of these RBIS compares to the reported use of classroom activities identified as critical components corresponding to specific RBIS. We used significance tests to determine whether critical components discriminated between users and nonusers.

To quantify the fidelity of the different RBIS, the percentage of required critical components implemented in conjunction with the RBIS was examined. Use of all critical components for each RBIS varied from 55-83%. Higher percentages (65-83%) were associated with RBIS that had one required critical component, such as concept tests. For RBIS with higher numbers (3-5) of critical components (such as Problem Based Learning and Collaborative Learning), though the percentage of users with complete fidelity (all critical components) was low (3-66%), the percentage that did not include any components was also low (most with 0% of users having no or only 1 critical component used in the classroom). To highlight the relationships between users and critical components, a Chi Square was completed comparing the RBIS to the different activities. Many of the activities (critical components) were found to have a significant relationship with the reported users of each RBIS, thus discriminating between users and nonusers.

Introduction

Over the past several decades, there has been sustained interest in reexamining the way the next generation of engineers is being educated. From what is being taught in the classroom with the introduction of the ABET learning outcomes[1] to the way it is being taught[2], university instructors are being called on to renovate their teaching. One way researchers are aiding in this effort is through the development of Research-Based Instructional Strategies (RBIS), such as active learning, cooperative learning, and inquiry learning for implementation in the classroom.

In recent years, researchers have begun working to investigate *if* these Research-Based Instructional Strategies (RBIS) are being used in the engineering[3-6], as well as physics[7] and geosciences[8] classroom. The results of these studies show an encouraging level of adoption among faculty members. However, more work is needed to ensure that faculty members are consistent when discussing if they use each RBIS.

Clear, consistent terminology is needed for each RBIS. Currently, within the RBIS literature, each RBIS is discussed with slight differences and varying characteristics, such as the distinction between cooperative and collaborative learning or between problem-based learning and project-based learning. To decrease confusion, there should be agreed upon characteristics for each RBIS that ensures it is being used optimally. These characteristics can also help define which characteristics are needed for increased learning and engagement.

Also, RBIS are "research-based" and, therefore, developed by researchers and discussed as research elements. Efforts need to be made to ensure that discussions of these RBIS are not only discussed within research circles, but also in ways practitioners can understand and make use of. Again, developing and defining specific activities to be done in the classroom can help bridge the gap between researchers and practitioners.

Within K12 education, there are much more explicit needs to ensure that programs follow specified guidelines that meet state and federal requirements. Evaluation of K12 educational initiatives routinely includes attention to fidelity of implementation, or how well the implemented intervention follows the original[9]. This provides evidence that the intended innovation or intervention is being implemented and any changes that are made are documented and tracked for impact. However, there have been limited studies investigating fidelity of implementation within engineering education[10].

This study used the fidelity of implementation framework to begin an investigation into the implementation of RBIS within the statics classroom, addressing the following research questions:

1) With what degree of fidelity are Research-Based Instructional Strategies (RBIS) being implemented within the statics classroom?
2) Do the critical components that characterize a RBIS discriminate between statics instructors who claimed use of the RBIS and those who did not?

We chose to focus this study on statics because it is a fundamental course for multiple engineering disciplines and a prerequisite for several upper level engineering courses. To investigate these research questions, we used a national survey of statics instructors. Their reported use of eight RBIS was compared to their reported use of classroom activities identified as critical components corresponding to RBIS use.

Literature Review

According to Rogers, early dissemination studies were based on the implicit assumption that all adoption was "an exact copying or imitation of how the innovation had been used previously in a different setting"[11]. More recently, it has become clear that studies must also consider the extent to which the innovation changes during the diffusion process, so researchers have begun considering the fidelity of implementation. A certain amount of adaptation can occur during implementation to aid in fitting the innovation into different contexts and classrooms. However, these changes need to be recorded and discussed when referring to an innovation.

Fidelity of implementation is broadly defined as the measure of how well an implemented intervention follows the original[9]. While there is limited research in engineering education specifically investigating fidelity of implementation, fields such as mental health, program evaluation, education, and human services have been conducting such investigations for several decades[12].

A key element of fidelity is the components that characterize the intervention. Century and colleagues called these the *critical components*, defined as the "essential features that must be measured to determine whether a program is present or not"[13]. Throughout the fidelity literature, these components are referred to with different terms, but each focuses on identifying the components that are necessary for fidelity. In this study, we will refer to them as *critical components*.

Mowbray and coworkers**[12]** reviewed the literature on fidelity of implementation to identify common steps used to establish, measure, and validate the fidelity criteria of an innovation. Author et al. developed a list of critical components using Mowbray et al. as a framework. The literature and a panel of experts with experience in the development and implementation of RBIS were consulted to create a list of critical components for each RBIS. A full list of RBIS and critical components can be found in Appendix A (Note: Having students "Participate in activities that engage them in course content through reflection and/or interaction with their peer" is indicative of all RBIS as these are all active learning strategies to improve engagement and was therefore not included in the table). This list was reviewed and discussed among the experts until consensus was reached. The critical components developed by Author et al. were used in this study. The list includes both required and indicative critical components. Required components are activities that would be absolutely necessary to claim that the RBIS is being used. For example, having students discuss problems in pairs is required for think-pair-share. Indicative components are generally associated with RBIS use, but are not required by the literature. For example, discussing problems in pairs is frequently indicative of active learning, but is not required for active learning to be used. For more information on the development and categorization of the critical components, refer to[10].

Methods

Instrument

The survey instrument was adapted from previous surveys of introductory physics instructors[14, 15] and electrical, computer[16] and chemical engineering[17] instructors.

The survey was divided into three sections. The first section asked faculty about their teaching and learning beliefs. The second section asked faculty to estimate the amount of class time spent on different activities generally associated with RBIS use—the required and indicative critical components. The third asked respondents about their level of use and knowledge of the 8 specific RBIS; descriptions of each RBIS were included. The fourth section included demographic information such as gender, rank, and frequency of attendance at teaching workshops. To quantify reliability of the instrument, Cronbach's alpha was calculated as 0.9208; indicating an acceptable level of reliability[18].

Data Collection

Statics instructors were identified by compiling a list of all accredited U.S. mechanical engineering programs (n = 285) as well as 7 civil engineering and 4 aeronautical/aerospace engineering programs at institutions that do not offer mechanical engineering. The University's Center for Survey Research (CSR) staff contacted each department via telephone with email follow-up to identify the statics instructors. The protocol included identifying which department was responsible for the course and following up as appropriate.

Each instructor was invited to complete the survey via a personalized e-mail signed by Paul Steif and Anna Dollár, established statics professors and researchers. The survey was administered in fall 2012.

Responses were screened to ensure respondents had taught statics within the last five years and had completed a majority of the survey items. Any participant who did not meet these characteristics was removed from the analysis, leaving 166 statics faculty with usable responses. The survey was sent to 764 faculty members; 166 responded, for a response rate of 22%.

Of the 166 usable responses, 20% of respondents were female and 62% male (18% did not respond); 13% were lecturers (i.e., not tenure track), 17% assistant professors, 25% associate professors, 17% full professors, and 10% listed their position as other (18% did not respond). The respondents came from a variety of engineering departments or programs: 34% mechanical engineering, 34% civil, 5% aerospace/aeronautical, 2% engineering mechanics, and 7% indicated "other" (18% did not respond).

Data Analysis

We operationalized an RBIS user as someone who indicated that they were currently using the RBIS (responded "I currently use it"). A non-user is an instructor who is not *currently* using the RBIS (responded any other way to the item). It was determined that an instructor spent time on an activity if they indicated spending more than 0% of class time on the activity. Due to the varying nature of each RBIS, some activities are meant to only take 1 or 2 minutes of class time which is less than 25% of class time. Instructors were not spending class time on an activity if they spent 0% of class time on the activity.

Fidelity was operationalized as the percentage of RBIS users who also spent class time on the required critical components. However, we identified between 1 and 5 required critical components for each RBIS. In the results section, we report the percentage of RBIS users who spent time on 5, 4, 3, 2, 1 and 0 required components (as relevant).

Since all respondents also answered questions about which classroom activities they spent time on, we can also use this data set to compare users to nonusers and determine whether various critical components are useful for discriminating between RBIS users and nonusers. We used Chi Square or Fisher's Exact tests to examine the relationships between RBIS use and the classroom activities identified as critical components using an alpha of 0.01 (due to the high number of comparisons). Unless indicated, all results are Chi Square.

Limitations

The limitations of the faculty survey approach include response bias from particularly conscientious instructors and self-reports of RBIS use. Both would tend to overestimate the level of RBIS use. However, the goal of this analysis is not to determine the proportion of engineering faculty members using RBIS. Readers are cautioned against using the data for this purpose. Rather, this analysis is focused on engineering faculty members' understanding and adaptation of the RBIS, many of which were not developed in engineering. Additional responses from faculty members who do not use RBIS, though likely more representative of the population, would have been of little use here. By triangulating two different types of survey items against each other, we can better describe the inherent limitations to faculty surveys of teaching, which are unlikely to go away any time soon, given the relative ease with which surveys generate large amounts of quantitative data.

Another limitation of the survey is not having an exact measure of how much time instructors spend on the activities and the influence of this on their RBIS use. The amount of time that is required for the activities varies between RBIS where some require a large amount of time and others require short amounts of time. Since this study we seeking to begin a conversation, investigating the appropriate amount of time that needs to be spent on each critical component is saved for future work.

Results and Discussion

The discussion of the results has been broken into two sections. The first looks at the number of required critical components that RBIS users are spending time on in their classroom, for all RBIS. The second uses Chi Square analysis to examine the critical components' ability to discriminate between the RBIS users and non-users, for 3 selected RBIS.

Fidelity of Implementation: Percentage of users spending time on critical components

To evaluate the fidelity of implementation for the RBIS, we first calculated the percentage of users who were also spending time on the required critical components. From Table 1, we can see that there are high levels of fidelity for many of the RBIS, ranging from 54% to 83%.

RBIS with just one required critical component (Concept Tests, Just-in-Time Teaching, and Inquiry learning) had more than three-quarters of the users also spending time on the required critical component. However, the challenge with these RBIS is that the fidelity is all or nothing; either they are using "all" (1) of the critical components or none of them.

The RBIS with multiple components (3 or more) have slightly lower percentages of complete fidelity (54% - 66%); however, they also have much lower percentages of users not using any of the critical components (0%). Most faculty members (95% - 100%) indicate using at least half of the components, which shows some level of fidelity, though not complete.

For the purposes of this exploratory study into fidelity of implementation, we are encouraged by the high number of respondents who are using a majority of the components. Further research is needed to investigate which components are often absent from implementation and the impact of neglecting that components on the effectiveness of the strategy.

Table 1: The percentage of RBIS users who spend class time on required critical components

	5	4	3	2	1	0
Problem Based Learning	**63%**	21%	11%	5%	0%	0%
Peer Instruction	N/A	**55%**	38%	7%	0%	0%
Collaborative Learning	N/A	N/A	**66%**	32%	2%	0%
Think-Pair-Share	N/A	N/A	**62%**	38%	0%	0%
Cooperative Learning	N/A	N/A	**54%**	46%	0%	0%
Concept Tests	N/A	N/A	N/A	N/A	**83%**	17%
Just-in-Time Teaching	N/A	N/A	N/A	N/A	**77%**	23%
Inquiry Learning	N/A	N/A	N/A	N/A	**65%**	35%

Fidelity of Implementation: The discriminating power of critical components between users and non-users

To better understand and illustrate the relationships between RBIS and their critical components, the next section presents more detailed results for three RBIS. These three were selected as representative of RBIS with low (1), medium (3), and high (>3) critical components. For each, we discuss the differences between users and non-users spending time on critical components.

Concept Tests

Concept Tests are multiple choice concept questions that use common student misconceptions as distracters (wrong answers)[19]. These can be implemented in larger classes through the use of clickers or similar voting methods that require students to commit to an answer before discussing the correct answer. This is a relatively simple RBIS in the sense that it has only one required critical component.

There was a significant difference between Concept Test users and non-users for the required activity of having students "answer multiple-choice conceptual questions with distracters that reflect common student misconceptions" (Table 2) with 90% of users also spending time on this activity as compared to 46% of non-users.

The indicative components did not show a significant difference between users and non-users. However, three of the indicative components were being used by 85% or more of concept test users (Table 2) (having students: "participate in activities that engage them with course content through reflection and/or interaction with their peers", "provide that answer(s) to a posed problem or question before the class can proceed", and "discuss a problem in pairs or groups"). The high percentage of users spending time on these activities shows that they are used in conjunction with Concept Tests, but also with other RBIS or in the general classroom as well.

Table 2: Concept Tests Required and Indicative Components

	Required/ Indicative	Faculty who use RBIS (n = 41) and spent time on activity	Faculty who **don't** use RBIS (n = 125), but spent time on activity	p-value
Answer multiple-choice conceptual questions with distracters that reflect common student misconceptions	Required	90%	46%	<0.001*
Use means other than clickers to 'vote' on the correct answer of a multiple choice question	Indicative	59%	38%	0.024
Use clickers to "vote" on the correct answer of a multiple choice question	Indicative	22%	10%	0.039
Participate in activities that engage them with course content through reflection and /or interaction with their peers	Indicative	85%	72%	0.085
Provide the answer(s) to a posed problem or question before the class can proceed	Indicative	85%	82%	0.582
Discuss a problem in pairs or groups	Indicative	90%	89%	1.00 [1]

* indicates a significant relationship with alpha = 0.01
[1] indicates Fisher's Exact Test used

Collaborative Learning

Collaborative Learning is a general term for any group work where students are working to a shared goal[20]. These techniques can be formal group projects or informal classroom activities in which students work with a partner. Collaborative learning has three required critical components.

Collaborative learning was considered to have moderate to high levels of fidelity with 66% of users spending class time on all three of the required critical components (Table 1). Each of these critical components was also found to differentiate between users and non-users (Table 3). “Discussing a problem in pairs or groups” was used by 97% of users and was found to be significantly different than non-users with a p-value of 0.001. Having students “work on problem sets or projects in pairs or small groups” was used by all (100%) of users and was found to have significantly different use when compared to non-users with a p-value less than 0.001. In Collaborative Learning, students “participate in group work for which they earn the same score as every other member of the group.” This critical component was found to be used by 66% of faculty who use Collaborative Learning and to be significantly different between users and non-users with a p-value less than 0.001.

When considering the indicative critical components, there is a high percentage of users who spend time on the components (66% - 89%) (Table 3). Of the faculty using Collaborative Learning, 86% reported having students “provide answer(s) to posed problem or question before the class session can proceed.” This is a high percentage, but 79% of non-users also spent time on this activity; mostly likely because this is a common activity not only with other RBIS, but also in general lecturing. The common critical component of having students “participate in activities that engage them with course content through reflection and/or interaction with their peers” was significantly different for users and non-users with a p-value less than 0.001. The key element of this activity that may have been stronger with users, when compared to non-users, is the latter part indicating that students have “interaction with their peers” which is the essence of Collaborative Learning.

Table 3: Collaborative Learning Required and Indicative Components

	Required/ Indicative	Faculty who use RBIS (n = 79) and spent time on activity	Faculty who **don't** use RBIS (n = 87), but spent time on activity	p-value
Work on problem sets or projects in pairs or small groups	Required	100%	63%	<0.001* [1]
Participate in group work for which they earn the same score as every other member of the group	Required	66%	24%	<0.001*
Discuss a problem in pairs or groups	Required	97%	82%	0.001* [1]
Participate in activities that engage them with course content through reflection and /or interaction with their peers	Indicative	89%	63%	<0.001*
Complete specially designed activities to "learn" course concepts on their own without being explicitly told	Indicative	66%	48%	0.023
Provide answer(s) to a posed problem or question before the class session can proceed	Indicative	86%	79%	0.252

* indicates a significant relationship with alpha = 0.01
[1] indicates Fisher's Exact Test used

Significant unexpected relationships were also found between Collaborative Learning and having students “report their group's finding to the entire class (formally or informally)” with 65% of users also spending time on this activity as compared to 17% of non-users (p-value <0.001). In practice, a number of faculty members may have their students complete projects as a group, then give a final presentation, giving one score for the group presentation explaining the larger number of Collaborative Learning users also spending time on reporting group findings. In future research, it would be beneficial to investigate the relationship between this activity and Collaborative Learning to more concretely discern if this activity is a critical component of this RBIS.

Unexpectedly, Collaborative Learning was also found to have a significant relationship with having students “work on problems or projects that require students to seek out new information not previously covered in class” with 38% of users also spending time on this activity as compared to 18% of non-users (p-value = 0.005). Again, this may refer to the potential problem or project-based nature of Collaborative Learning and having students work in a way that requires additional information. Further investigation is needed to determine the exact relationship between this activity and Collaborative Learning.

The last unexpected relationship was between Collaborative Learning and having students "participate in group work for which the assessments are designed so that individuals may earn different scores for their work on the assignments" with 70% of users also spending time on this activity as compared to non-users at 40% (p-value < 0.001). For the purposes of this study, we defined Collaborative Learning as having students be evaluated as group (one score) ; however, a higher percentage of faculty who indicated using Collaborative Learning also indicated they give individual evaluations for group work (characteristic of cooperative learning), indicating that this may not be a universal definition. More work is needed to clearly state what activities are characteristic of Collaborative Learning versus Cooperative Learning and to encourage faculty to report exactly what they are doing when they say they are using Collaborative or Cooperative Learning.

Problem-Based Learning (PBL)

Problem-Based Learning (PBL) centers around an open-ended, authentic problem that requires students to identify objectives and needs to find a solution for the problem. In this environment, the instructors take on the role of facilitator rather than source of information[21]. PBL is a complex RBIS to study in terms of fidelity because it has four required critical components and an additional three indicative critical components.

Problem-Based Learning had a fairly high level of fidelity with 65% (Table 1) of users spending time on all five required critical components. Additionally, four of the five components discriminated between users and non-users (Table 4). That is, we found a statistically significant difference between PBL users and nonusers for three of the five required critical components. The required component, "discuss a problem in pairs or groups," that was not significant was used by 100% of the PBL users, but also used by a high percentage (86%) of non-users. This activity is mapped to several other RBIS, so it is not surprising that non-PBL users would also spend time on this activity in class. Also, the required component "work on projects or situations from real engineering practice" was not significant with 92% of reported users also spending time on this activity as compared to 78% of non-users.

There was considerable fidelity among the indicative components for PBL as well, with over 70% of users also using two indicative components. The third component was used by a lower percentage of users, but if we look at the indicative components, two of the components ask about assessing the student work in groups (receiving one grade per group or individual grades). Many faculty may use just one of these components because they both focus on grading. It was also shown that a majority of PBL users (71%) give one grade per group rather than individual grades within the team (42%). A significant difference was also found between PBL users and non-users for assigning one group-grade for work completed as a group.

Table 4: Problem Based Learning Required and Indicative Components

	Required/ Indicative	Faculty who use RBIS (n = 38) and spent time on activity	Faculty who **don't** use RBIS (n = 128), but spent time on activity	p-value
Complete specially designed activities to "learn" course concepts on their own without being explicitly told	Required	84%	48%	<0.001*
Work on problems or projects that require students to seek out new information not previously covered in class	Required	82%	46%	<0.001*
Work on problem sets or projects in pairs or small groups	Required	97%	76%	0.002* [1]
Discuss a problem in pairs or groups	Required	100%	86%	0.014 [1]
Work on projects inspired by problems or situations from real engineering practice.	Required	92%	78%	0.059 [1]
Participate in group work for which they earn the same score as every other member of the group	Indicative	71%	36%	<0.001*
Participate in activities that engage them with course content through reflection and /or interaction with their peers	Indicative	89%	71%	0.020 [1]
Participate in group work for which assessments are designed so that individuals may earn different scores for their work on the assignments	Indicative	42%	23%	0.024

* indicates a significant relationship with alpha = 0.01
[1] indicates Fisher's Exact Test used

A significant difference was also found between PBL users and non-users with respect to spending time having students "report their group's findings to the entire class (formally or informally)" ($p < 0.001$) with 66% of users also spending time on this activity as compared to 32% of non-users. This critical component was not identified for PBL, but it was included in the analysis because it belonged to other RBIS. This unexpected result may imply that as part of problem based learning, instructors have their students report their findings to the class in the form of formal presentations at the end of the semester. Further investigation will be needed to explore the nature of this relationship.

Conclusion

Fidelity of implementation is an important lens for investigating innovative, research-based instructional strategies implemented in engineering education. Overall, this study has shown a promising level of fidelity among engineering sciences faculty members. Most of the faculty members who identified as users of a specific RBIS, also indicated that they use at least one of the corresponding activities identified by the literature as necessary for implementing that RBIS. It should be noted that the RBIS with one required critical components (such as concept tests) had higher levels of overall fidelity when compared to the more complex RBIS.

Encouraging progress was also made in identifying the critical components that distinguish RBIS users from nonusers. Many critical components where used significantly more by users of the

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RBIS when compared to non-users. However, a number of the components did not show a difference indicating that the critical component was not an independent indicator of the RBIS or that it did not show a relationship with the RBIS. Additionally, some activities that were not intended to differentiate between users and non-users did present a significant difference. Further research is needed to investigate these relationships.

Fidelity of implementation is a fairly unexplored area within engineering education, and more research is needed. The future research needed in this area falls into a number of different categories.

First, further research should be done to establish the critical components of commonly used RBIS. This study began this process, but further investigation is needed. Direct measures, such as classroom observations of RBIS use, will help explore the unexpected relationships found throughout this study and further develop the critical components of each RBIS.

Another direction for future research should be integrating fidelity into the development of new instructional strategies. Developing the critical components alongside the strategy will help the initial dissemination of the strategy and will help to avoid confusion between the new strategies and previously developed ones.

The final direction for future research is to explore the reasons for varying levels of fidelity. To better understand and improve fidelity, it is important to understand the factors that influence it. What characteristics of the instructor, RBIS, or developer impact fidelity? Which factors are most influential? One example of a future study would be comparison between critical components identified by developers and faculty users. Finding the similarities and differences between these two groups could offer insight into why there are varying levels of fidelity.

Implications for Practice

Fidelity of implementation has many implications for teaching and learning in undergraduate engineering. First, fidelity helps to ensure researchers and practitioners are using the same language in their conversations. High fidelity ensures that when someone indicates use of concept tests, their audience knows what activities are being implemented in association with concept tests.

Also, a focus on fidelity of implementation offers a more explicit description of how to use the RBIS because it is broken into critical components. So, using fidelity as a framework for faculty development offers opportunities to ensure it is made clear what the expectations for the RBIS are and the ways to integrate the critical components into the classroom.

Another implication for this work is that it draws attention to the issue that when faculty use an RBIS with unacceptable levels of fidelity, the benefits of the RBIS may be compromised, potentially hindering student learning.

Also, as a note to researchers developing new RBIS, faculty members are more likely to implement the RBIS with full fidelity if there are only a few required critical components. So keeping new RBIS simple may help them be adopted in the classroom.

Examining and reporting on the Fidelity of Implementation is also not limited to the RBIS discussion. For many other research-to-practice setting, such as extra-curricular activities or assessment programs, reporting on the critical components that are required for the program to be effective is very important.

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Appendix A: Full list of RBIS, critical components, and reference

Just-In-Time Teaching	Required	Spent time discussing pre-class assignments which helped you re-evaluate student learning and adjust your lecture "just in time"	[1-5]
Inquiry Learning	Required	Work on problems or projects that require students to seek out new information not previously covered in class	[2, 3, 6]
	Indicative	Complete specifically designed activities to "learn" course concepts on their own without being explicitly told	[2, 3, 6]
Peer Instruction	Required	Answer multiple choice conceptual questions with distracters that reflect common student misconceptions	[7-11]
	Required	Use clickers to 'vote' on the correct answer of a multiple choice question	[7, 10, 12]
	Required	Discuss a problem in pairs or groups	[7-11]
	Required	Provide answer(s) to a posed problem or question before the class session can proceed	[7, 9-11]
	Indicative	Use means other than clickers to 'vote' on the correct answer of a multiple choice conceptual question	[8, 10, 11]
	Indicative	Report their group's findings to the entire class	[10, 13]
Concept Tests	Required	Answer multiple-choice conceptual questions with distracters that reflect common student misconceptions	[9-11, 13-16]
	Indicative	Use means other than clickers to 'vote' on the correct answer of a multiple choice question	[10, 13, 14, 16]
	Indicative	Use clickers to "vote" on the correct answer of a multiple choice question	[10, 14, 16]
	Indicative	Provide the answer(s) to a posed problem or question before the class can proceed	[10, 13, 14]
	Indicative	Discuss a problem in pairs or groups	[10, 13, 14]
Think-Pair-Share	Required	Report their group's findings to the entire class (formally or informally)	[14, 17-19]
	Required	Discuss a problem in pairs or groups	[14, 17-20]
	Required	Provide answer(s) to a posed problem or question before the class session can proceed	[18-20]
Problem-Based Learning	Required	Complete specially designed activities to "learn" course concepts on their own without being explicitly told	[2, 3, 21-23]
	Required	Work on problems or projects that require students to seek out new information not previously covered in class	[2, 3, 21-23]
	Required	Work on problem sets or projects in pairs or small groups	[2, 3, 21-23]
	Required	Discuss a problem in pairs or groups	[2, 3, 21-23]
	Required	Work on projects inspired by problems or situations from real engineering practice	[2, 3, 21-24]
	Indicative	Participate in group work for which they earn the same score as every other member of the group	[24, 25]
	Indicative	Participate in group work for which assessments are designed so that individuals may earn different scores for their work on the assignments	[23-25]
Collaborative Learning	Required	Work on problem sets or projects in pairs or small groups	[26-28]
	Required	Participate in group work for which they earn the same score as every other member of the group	[24, 26]
	Required	Discuss a problem in pairs or groups	[26-28]
	Indicative	Complete specially designed activities to "learn" course concepts on their own without being explicitly told	[26, 27]
	Indicative	Provide answer(s) to a posed problem or question before the class session can proceed	[26]
Cooperative Learning	Required	Participate in group work for which the assessments are designed so that individuals can earn different scores for their work on the assignment	[13, 24, 29, 30]
	Required	Work on problem sets or projects in pairs or small groups	[13, 27, 28, 30]
	Required	Discuss a problem in pairs or groups	[27, 28, 30]
	Indicative	Report their group's findings to the entire class (formally or informally)	[13, 28]
	Indicative	Complete specifically designed activities to "learn" course concepts on their own without being explicitly told	[26, 28]
	Indicative	Provide the answer(s) to a posed problem or question before the class can proceed	[13, 30]

Having students "Participate in activities that engage them in course content through reflection and/or interaction with their peer" is indicative of all RBIS as these are all active learning strategies to improve engagement and was therefore not included in the table.

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