Engineering Educators Bringing the World Together
2025 ASEE Annual Conference & Exposition
Palais des congrès de Montréal, Montréal, QC • June 22–25, 2025
Paper ID #45782

Work in Progress: Refining a Rigid Body Dynamics Concept Inventory with Expert Feedback and Preliminary Student Testing

Dr. Amie Baisley, University of Florida

Amie Baisley is currently an Instructional Assistant Professor at the University of Florida teaching primarily 2nd year mechanics courses. Her teaching and research interests are alternative pedagogies, mastery-based learning and assessment, student persistence in their first two years, and faculty development.

Dr. Brian P. Self, California Polytechnic State University, San Luis Obispo

Brian Self obtained his B.S. and M.S. degrees in Engineering Mechanics from Virginia Tech, and his Ph.D. in Bioengineering from the University of Utah. He worked in the Air Force Research Laboratories before teaching at the U.S. Air Force Academy for sev

Dr. Julian Ly Davis, University of Southern Indiana

Jul Davis is an Associate Professor of Engineering at the University of Southern Indiana in Evansville, Indiana. He received his PhD in 2007 from Virginia Tech in Engineering Mechanics where he studied the vestibular organs in the inner ear using finite element models and vibration analyses. After graduating, he spent a semester teaching at a local community college and then two years at University of Massachusetts (Amherst) studying the biomechanics of biting in bats and monkeys, also using finite element modeling techniques. In 2010, he started his career teaching in all areas of mechanical engineering at the University of Southern Indiana. He loves teaching all of the basic mechanics courses, and of course his Vibrations and Finite Element Analysis courses.

Dr. Phillip Cornwell, U.S. Air Force Academy

Phillip Cornwell is a Professor of Mechanical Engineering at the United States Air Force Academy and an Emeritus Professor of Mechanical Engineering at Rose-Hulman Institute of Technology. He received his Ph.D. from Princeton University in 1989, and his current interests include structural dynamics, structural health monitoring, and undergraduate engineering education. Dr. Cornwell received the SAE Ralph R. Teetor Educational Award in 1992, the Dean's Outstanding Teacher Award at Rose-Hulman in 2000, and the Rose-Hulman Board of Trustees' Outstanding Scholar Award in 2001. He was one of the developers of the Rose-Hulman Sophomore Engineering Curriculum and the Dynamics Concept Inventory. Additionally, he is a co-author of Vector Mechanics for Engineers: Dynamics, by Beer, Johnston, Cornwell, and Self. In 2019, Dr. Cornwell received the Archie Higdon Distinguished Educator Award from the Mechanics Division of ASEE, and in 2023, he was honored with the Ralph Coats Roe Award from the Mechanical Engineering Division of ASEE.

Dr. Geoffrey Recktenwald, Michigan State University

Geoff Recktenwald is a member of the teaching faculty in the Department of Mechanical Engineering at Michigan State University. Geoff holds a PhD in Theoretical and Applied Mechanics from Cornell University and Bachelor degrees in Mechanical Engineering and Physics from Cedarville University. His research interests are focused on best practices for student learning and student success. He is currently developing and researching SMART assessment, a modified mastery learning pedagogy for problem based courses. He created a multi-year integrated system design (ISD) project for mechanical engineering students. He is a mentor to mechanical engineering graduate teaching fellows and actively champions the adoption and use of teaching technologies.

Work in Progress: Refining a Rigid Body Dynamics Concept Inventory with Expert Feedback and Preliminary Student Testing

Abstract

Following the initial development of a new Rigid Body Dynamics Concept Inventory (RBDCI), our ongoing efforts have focused on refining the instrument through targeted feedback collection. The two key sources of feedback include a survey from experts in the field and initial testing of the concept questions with students. The expert survey gathered feedback on the 11 proposed concepts identified through our previous efforts and the original DCI Delphi study results. Experts were asked to rate the importance of each concept and estimate the percentage of students who struggle with each one. These results provided valuable insights for refining and narrowing down the number of concepts tested in the RBDCI.

Additionally, we piloted subsets of the proposed concept questions with a diverse group of students from various universities. The students answered all questions for each subset, and for select questions, they also provided written responses, rated their confidence, and assessed the perceived effectiveness of the questions. The analysis of the student results identified areas of strength and weakness in the current questions. The results revealed misunderstandings related to problem statements and figures, and improvements were made to questions that involved multiple concepts. It was important to refine each question to effectively target only one specific rigid body dynamics concept.

The combination of expert feedback and student testing will continue to improve and lead to a finalized RBDCI that can be used by all mechanics instructors. Our current work involves further iterations of student testing with problem subsets to continue refining and clarifying the questions. This paper presents the key findings from the expert survey and preliminary student testing, highlights the changes informed by these results, and outlines the path forward toward a validated Rigid Body Dynamics Concept Inventory.

Introduction

Concept Inventories have become useful tools to identify student misconceptions across numerous disciplines including physics, engineering, biology, and geology [1]. These concept inventories are used as diagnostic assessments that can identify how students understand, or misunderstand, principles of the different topics. Many of these inventories have also helped inform instructional practices or evaluate the changes in instructional methods [2]. One of the earliest and influential examples was the Force Concept Inventory (FCI) which helped lead change to instruction methods used in physics [3]. Informed by the success of the FCI, an original Dynamics Concept Inventory (DCI) was developed to assess and update Dynamics instruction with a focus on particle dynamics [2, 3]. The original DCI has been downloaded over 150 times from the Concept Warehouse website [1, 2, 4, 5]. The results from the original DCI have provided insights into common student misconception in particle dynamics, while also identifying instructional differences amongst teaching approaches [6-8]. The DCI covers particle dynamics well, but it does not adequately address rigid body dynamics which is a topic that is challenging for many students. Research by Fang has identified that rigid body motion and rotational dynamics are considered by students as some of the most difficult concepts in dynamics courses [9].

Recognizing this gap and need for a focus on rigid body problems, a research team has worked to develop a new Rigid Body Dynamics Concept Inventory (RBDCI). The RBDCI focuses on rigid body concepts which expands on dynamics topics not included in the original DCI with the intent for it to become a targeted diagnostic tool to address the conceptual challenges associated with rigid body dynamics. The initial proposal for the RBDCI included 11 core concepts and was presented at the 2024 ASEE Annual Conference and Exposition [10]. Table 1 lists the initial 11 concepts proposed for the RBDCI.

Table 1: Initial 11 concepts proposed for the new Rigid Body Dynamics Concept Inventory (RBDCI)

Concept	Title
1	Different points on a rigid body have different velocities and accelerations.
2	The inertia of a body affects its acceleration and velocity.
3	The forces and acceleration of a rigid body are dependent on one another.
4	A rigid body can have both translational and rotational kinetic energy.
5	In general, the total mechanical energy is not conserved during an impact.
6	Coriolis acceleration occurs in rotating reference frames.
7	The angular momentum of a rigid body depends on the reference point.
8	If the net external force F on a rigid body is not zero, then there is an acceleration of the center of mass of that body.
9	Angular velocities and angular accelerations are properties of the rigid body.
10	Points on an object that is rolling without slipping have velocities and accelerations that depend on this constraint
11	The action of friction opposes the relative velocity at the contact point. Or acts to prevent relative motion at the contact point.

As part of the development process of the RBDCI, it was important to ensure reliability and validity of the proposed concepts. The team used a Delphi method to gather feedback amongst the experts that these proposed concepts are fundamental for rigid body dynamics. The Delphi method has been used in many different fields as a process to get consensus on topics from experts [11]. For the RBDCI, the same process was used that was implemented in the second round of Delphi testing done for the original DCI [2]. This method ensures that the RBDCI reflects expert opinion on the important concepts and instructional needs for rigid body dynamics and provides feedback to the research team to further refine and reduce the list of proposed concepts.

Expert Survey and Feedback

One of the next steps in the development of the RBDCI is to finalize a set of 10 concepts from the initial list of 11 presented in Table 1 based on feedback from the experts and discussion amongst the team. The decision to reduce the inventory to 10 concepts is based on the practical considerations of test length and depth. The final version of the RBDCI will include three questions per concept resulting in a 30-question inventory. This balances content coverage providing adequate diagnostic results for each concept while keeping the length manageable for test takers. Following the presentation of the initial concepts at the 2024 ASEE Conference and Exposition, a Qualtrics survey was designed and distributed to experts in the field of mechanics. The survey was developed based on the same Delphi process that had been used in expert surveys for other concept inventories [2, 11]. The survey was shared through the ASEE Mechanics Division mailing list in two sperate communications: a stand-alone email and a follow-up opportunity as part of the Mechanics Division Fall Newsletter. This allowed broad participation from instructors who are part of the division to participate in the survey.

The survey was completed anonymously but included two experience-related questions about the number of years the responder had been an instructor and the number of semesters they had taught undergraduate dynamics. Table 2 provides a breakdown of the experience levels for the faculty that responded to the survey.

Table 2: Experience level of faculty members surveyed

Years as Instructor	No. of Faculty	Semester Teaching Dynamics	No. of Faculty
1-5	2	1-5	5
6-12	3	6-10	1
12-20	3	11-15	2
20+	3	16+	3

There was a total of 11 faculty who completed the entire survey. An additional six faculty started the survey but did not rate the concepts, so their responses were excluded from the analysis. The instructors' experience was evenly distributed across the different categories for teaching duration, while nearly half of the responders had taught introductory dynamics for five semesters or less.

Following the experience questions, the survey asked each responding faculty to rate the importance of the 11 concepts relative to an introductory engineering dynamics course and to estimate the percentage of students who understand the concept at an acceptable level at the end of the introductory dynamics course. The ratings were provided on a scale of 0 to 10, with 0 indicating "I do not cover this topic". The remaining rating scale was 1 – is not important/less than 10% of students understand, to 10 – very important/between 90%-100% of students understand. Table 3 summarizes the average ratings for each concept

Table 3: Results from experts' evaluations of proposed concepts in terms of importance and student understanding

Concept	1	2	3	4	5	6	7	8	9	10	11
No. Faculty	11	11	11	10	10	8*	9	11	11	10	9*
Importance	9.55	9.27	9.91	9.20	8.40	6.50	8.11	9.09	9.00	8.40	7.44
Student Understanding	7.82	7.45	9.27	6.80	6.10	3.78	5.78	7.64	7.09	6.40	5.50
Difference (Importance – Understanding)	1.73	1.82	0.64	2.4	2.3	2.72	2.33	1.45	1.91	2	1.94

*For Concept 6 and 11 there was one faculty member that selected "I do not cover this topic" for Importance but gave a numerical rating for the Student Understanding question.

The trends revealed that the concepts rated higher in importance often had higher student understanding ratings. This correlation might reflect the emphasis placed on these concepts during instruction or a result of the nature of the concept and how accessible it is within the dynamics curriculum. Figure 1 illustrates the relationship between importance and student understanding ratings, highlighting the consistent trend across most concepts.

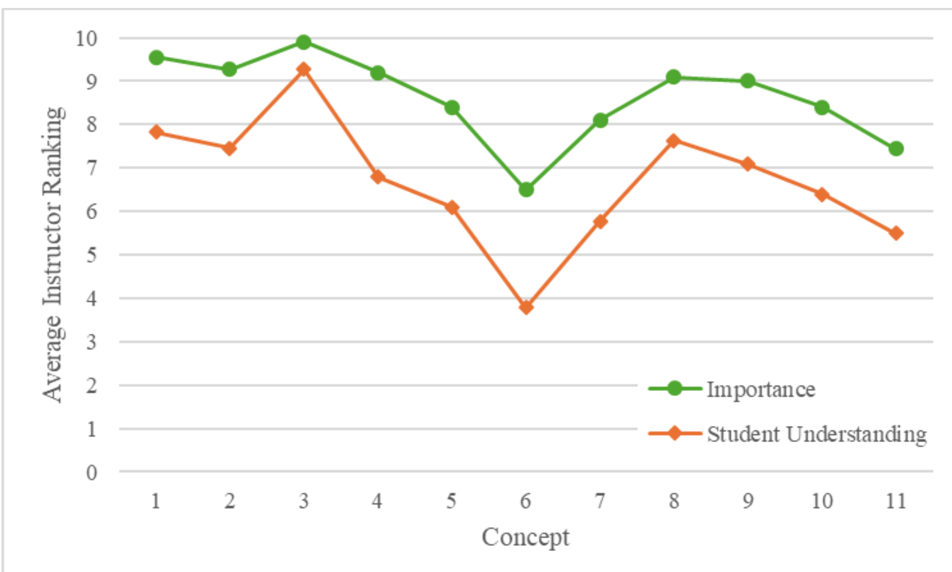


Figure 1: Average Ranking for Importance and Student Understanding of Each Concept

Notably from Figure 1, Concept 3 has the highest rating in student understanding with an estimated 90% or more of students that achieve acceptable understanding by the end of the semester. Concept 6 had the lowest rating for both importance and understanding, with several faculty indicating that they did not cover it.

After reviewing the expert feedback, it was determined that all 11 concepts were important to rigid body dynamics (all receiving an importance rating above 6). However, this feedback will be considered when reducing the number of concepts for the final RBDCI which aims to have only 10 concepts. The survey also included open-ended questions allowing instructors to:

1) Identify any concepts that need more clarification.
2) Suggest additional rigid body dynamics concepts.
3) Provide general comments or suggestions for the RBDCI.

There were several responses to each of these prompts that are being discussed amongst the team and being used to clarify the 11 concept titles. The responses also helped identify any possible gaps or missing information. The expert feedback was instrumental in guiding the next phase of the RBDCI development, but based on these results, all 11 concepts were still included to get additional data from the student testing phase. This will provide multiple data sources of information that will be used to evaluate which concepts should be included in the final RBDCI.

Initial Student Testing

In parallel with surveying the experts, the project team collaboratively drafted possible problems for each concept. Each member proposed multiple questions, which were reviewed and modified through team discussions. This process narrowed down the questions and finalized the answers for the first round of student testing. Questions were uploaded to the Concept Warehouse (https://conceptwarehouse.tufts.edu/cw/), a free online tool that houses concept questions, several concept inventories, as well as instructional tools. Table 4 summarizes the initial number of draft questions per concept along with the corresponding Concept Warehouse problem numbers.

Table 4: Summary of concept questions developed and corresponding Concept Warehouse numbers

Concept	Number of draft questions	Concept Warehouse numbers
1	6	7358, 7359, 7360, 7361, 7371, 7372
2	2	7334, 7341
3	6	7367, 7375, 7376, 7377, 7378, 7379
4	3	7336, 7337, 7335
5	5	7362, 7363, 7370, 7373, 7374
6	3	7338, 7339,7340
7	4	7364, 7366, 7368, 7369
8	0	-
9	5	7395, 7396, 7397, 7398, 7399
10	4	7404, 7408, 7411, 7415
11	0	-

The target was to have 3-6 questions per concept for testing and based on the results the questions will be revised or reduced. Two concepts (8 and 11) did not have any problems created for the first round of testing due to the team prioritizing other concepts and a lack of consensus on suitable rigid body questions at the time of this paper. These concepts will be tested in the next phase of testing.

The initial student testing was conducted across the five universities represented by the project team, ensuring a diverse student population. Each team member was responsible for testing up to four questions per concept and focusing on two specific concepts with some additional questions included at their discretion. Due to varying enrollment sizes, class types, and question distributions, the number of students tested was not evenly distributed across the questions. Table 5 presents the percentage of students who answered each concept question correctly, along with the total number of students tested on each question provided in parentheses.

Table 5: Percent of students that correctly answered each question during initial student testing

Concept	Question 1	Question 2	Question 3	Question 4	Question 5	Question 6
1	60% (10)	44.4% (9)	-	100% (10)	-	90.6% (32)
2	31.4% (86)	79.5% (39)	-	-	-	-
3	60.5% (38)	67.2% (61)	35.1% (37)	73.7% (38)	-	68.4% (38)
4	50.8% (128)	39.5% (129)	40.2% (127)	-	-	-
5	50% (72)	40% (65)	46.9% (64)	80.6% (62)	78.9% (71)	-
6	22% (59)	18.4% (109)	22% (59)	-	-	-
7	38.1% (42)	80.5% (41)	55.6% (18)	68.3% (41)	-	-
9	65.2% (23)	62.5% (32)	95.8% (24)	73.5% (34)	76.5% (34)	-
10	10.5% (38)	36.8% (38)	10.5% (38)	31.6% (38)	-	-

The initial testing results provide insights into the difficulty of each concept and question. The most notable results include:

- Two questions from Concept 1 and one question from Concept 9 had over 90% correct responses, suggesting that these questions or their answer choices might by too easy. While an easy question can serve as a baseline, revising the distractors can help better identify student misconceptions.
- For Concept 10 there were two questions that had less than 11% correct responses. These questions included more than five answer options each, potentially leading to confusion with the large variety of choices. The results for these questions can help refine the answer choices to improve clarity.

- Concept 9 had the highest percentages overall, while Concept 6 had the lowest percentages across the questions. This could reflect the level of understanding that the students have with these concepts or their familiarity with the topics.
- Most of the questions proved challenging to students, with performance varying across the questions in the same concept. Having success with one question did not correlate to success in the other questions for that concept.

These findings will guide the revisions for the next round of testing to ensure a balance between question difficulty and conceptual coverage.

Analysis of Question-Specific Results

Comparing student responses within the same concept is a critical aspect of the question design and refinement process. For example, looking at two questions from Concept 3 – "The forces and acceleration of a rigid body are dependent on one another," highlights how students perform differently based on the figure shown, question phrasing, and answer options. Figure 2 includes two questions that can be compared from Concept 3.

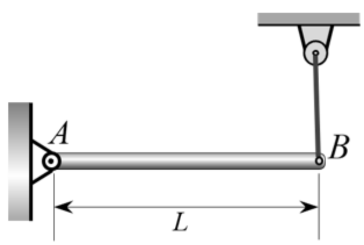
Concept Warehouse Question 7376	A uniform rod of length L and weight W is supported as shown. Before the cable is cut, the reaction at A is equal to half the weight of the bar. At the instant right after the cable at B is cut, which statement is true about the reaction at A?  A. The reaction at A is equal to the total weight W B. The reaction at A is larger than W C. The reaction at A is less than W D. The reaction at A remains unchanged
Concept Warehouse Question 7377	The two rods have the same mass and length and are held in the horizontal position as shown. Bar A is released from rest and Bar B is given an initial angular velocity, ω. What statement is true about the reaction force at the pin O at the instant shown?  A. The reaction forces are equal B. The reaction force for rod A is greater C. The reaction force for rod B is greater D. The reaction force will be zero for both cases

Figure 2: Examples of two RBDCI questions for Concept 3

The results are summarized for these two Concept 3 questions in Table 6.

Table 6: Comparison of student responses for Concept 3 questions

Answer	Question 7376	Question 7377
A	13	9
B	8	1
C	**13**	**28**
D	3	0
Total No. Students	37	38
% Correct	**35.1%**	**73.7%**

The results indicate that Question 7377 is an easier question for the students, as nearly 74% answered correctly. This may be the result of having a lack of strong distractor answers. It could also indicate that students understand or have the intuition that an initial angular velocity in the system results in a higher reaction force at the pin. Question 7376 had lower success, around 35%, likely because the answer is not immediately obvious from the figure. The Answer A, a static solution, was a desirable distractor for the students to select, but the student responses were distributed across all the answer choices suggesting student confusion or misconception for that problem.

Despite these differences in the results, the project team values both questions for the final RBDCI. There will be discussions to develop better distractors, particularly replacing Answer D for Question 7377, to further improve the quality of the question.

Another example of how initial student testing will inform question refinement is provided by Concept Warehouse Problem 7408, which is shown in Figure 3.

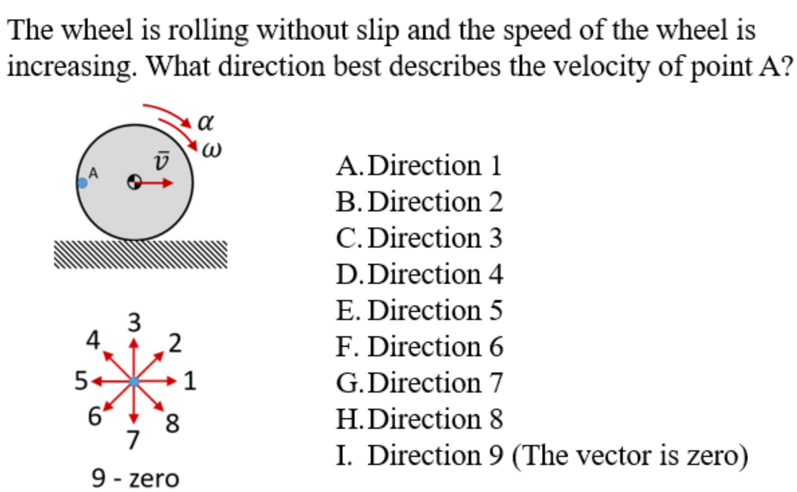


Figure 3: Example of an RBDCI question for Concept 10

The results for this question are summarized in Table 7.

Table 7: Student responses for Concept 10 question

Answer	**Question 7408**
A	4
B	**14**
C	15
D	1
E	2
F	0
G	0
H	1
I	1
Total No. Students	38
% Correct	**36.8%**

These results suggest that Answers A and C are good distractors, as they attracted a decent amount of student responses. However, the other answers were rarely selected and do not make good distractors for this question. This data supports reducing the number of answer choices to four or five by focusing on the most chosen distractors.

A key consideration for this question and others like it is whether it is best to keep the current set of nine directional answer options. There is much of the education literature that supports fewer multiple-choice answers including reducing all multiple-choice tests to three answer options, which could have benefits on reducing cognitive load and allowing for more items to be tested [12]. However, it was decided, at least for the initial testing phase, to maintain consistent direction choices for all questions that included a directional wheel to simplify the test-taking experience. There are currently 10 questions that use a directional wheel for the answers with varying correct answers amongst the nine wheel options, so to prevent the students from having to interpret a new set of directions for each questions it was decided that a uniform directional wheel will be used to minimize variability on answer choices to allow students to focus on answering the question rather than interpreting each new set of directions for each question. The project team is evaluating the trade-off of reduced answers compared to consistency across the test when finalizing the question design.

In addition to the quantitative results for each question, the team collected qualitative responses to gain deeper insights into the student thoughts and effectiveness of each question. The students could comment on how they approached the problem and their thoughts on the question effectiveness. Their responses are currently being analyzed and categorized to identify the different strategies students used to solve the problem. This will involve correlating the students' thought process with their answer selection. This correlation will create a confusion matrix for each question with four categories including: correct answer with helpful reasoning, correct answer with unhelpful reasoning, incorrect answer with helpful reasoning, and incorrect answer with unhelpful reasoning. These matrices will provide an understanding of student performance and reasoning patterns.

Additionally, categorizing student thought processes into themes will provide further insights into how students respond to specific concepts. These themes will further help improve question effectiveness, problem statement ambiguity, distractor answer choices, and identify any major misconceptions students may have about rigid body dynamics concepts. The combination of the quantitative and qualitative feedback is key to improving the RBDCI to become a useful tool to assess undergraduate students in rigid body dynamics concepts.

Discussion

The refinement process for the RBDCI has presented several challenges. It has been important to balance the cognitive load and question clarity while also creating opportunities to diagnose student understanding from the results that could be valuable to the instructor. To achieve these goals, it is essential that each question effectively targets only a single concept while aligning with common instructional practice. It is an iterative process, but the feedback from experts and students has been crucial in supporting the development. These results have identified several opportunities for improvement to both the concept titles and the questions.

The expert survey provided insights into the importance and clarity of the proposed concepts. There were several concept titles that faculty offered recommendations for rephrasing, clarity, or slight modifications. The concepts rated as less important or with lower ratings for student understanding will require careful consideration when finalizing the RBDCI's 10 concepts.

The student testing revealed significant variation in question performance across the concepts. The questions with the lowest correct response, such as those in Concept 10, are being reevaluated to improve clarity and answer choices. While the questions with the highest correct response, like those in Concept 1 and 9, are being evaluated to determine whether the answer choices need adjustment to improve the diagnostic results to better understand misconceptions. The creation of better distractor answers based on common student misconceptions is a key priority. The qualitative student responses will also add to the ability to identify these misconceptions to refine the questions accordingly. This process will ensure that the RBDCI test results will assess both student understanding and provide instructors with insight on the areas of weakness for their students.

Next steps

The project team is currently focused on analyzing the qualitative results from the first round of student testing, refining questions based on the feedback received, and preparing for a second round of student testing. The second round will involve a new cohort of students, offering fresh data on the RBDCI. There will be an emphasis on addressing gaps identified during the initial testing, such as the lack of questions for Concepts 8 and 11, while continuing to improve clarity and refine the other concepts.

As part of the next phase of development, it is important to establish validity and reliability of the RBDCI [2]. To guide this process, the Evidentiary Validity Framework will be used, which has been used for other concept inventories to establish validity [12]. This framework requires gathering multiple sources of evidence to support the interpretation and intended use of the test scores including evidence based on the concepts tested, the responses, the likelihood for misconceptions, and the consequences of the results [13]. The validation efforts include analyzing the question specific responses with the student's qualitative responses to determine misconceptions, surface level misunderstanding, guessing, or insight into how the students interpret the questions. The team will also use statistical analysis methods like item-total correlations to assess the consistency of questions within in the same concept. This will identify questions that have inconsistent performance or fail to discriminate between student understanding and may result in further revision or removal from the inventory. A final source of evidence will include collecting feedback from instructors who use the RBDCI in their classroom. This is evidence for consequential validity to understand how the inventory can inform instruction and to evaluate the practical use of the RBDCI.

Reliability will be evaluated by testing the inventory across diverse student populations at multiple institutions. Consistency of question performance across different cohorts will evaluate the reliability and generalizability of the RBDCI. Other reliability metrics, like Cronbach's alpha, will be calculated to assess the internal consistency of the overall inventory and individual concepts.

Through addressing the feedback and challenges at each iteration, the team aims to develop a robust and practical tool to measure student understanding of rigid body dynamics. The RBDCI is intended to identify areas of weakness and student misconception, but also become a valuable resource to enhance dynamics education and support deeper student learning of rigid bodies in dynamics courses.

References

[1] D. L. Evans *et al.*, "Progress on concept inventory assessment tools," in *Proceedings - Frontiers in Education Conference, FIE*, Institute of Electrical and Electronics Engineers Inc., 2003, p. T4G1-T4G8. doi: 10.1109/FIE.2003.1263392.

[2] G. L. Gray, D. Evans, P. Cornwell, F. Costanzo, and B. Self, "Toward a Nationwide Dynamics Concept Inventory Assessment Test," *American Society for Engineering Education*, 2003.

[3] Hestenes, D., M. Wells, and G. Swackhamer (1992) "Force Concept Inventory," The Physics Teacher, 30, pp. 141–158.

[4] P. J. Cornwell and B. P. Self, "The Dynamics Concept Inventory (DCI)-The Past, Present, and Future," in *Proceedings of the American Society for Engineering Education*, 2020.

[5] G. Gray, F. Costanzo, and D. Evans, "The dynamics concept inventory assessment test: A progress report and some results," *American Society for Engineering Education*, Online, 2005, Available: http://www.esm.psu.edu/dci/papers/ASEE-DCI-Portland.pdf.

[6] J. L. Davis and S. L. Arena, "WIP: Implementation of a Dynamics Concept Inventory – Before and After a Dynamics Class" in *Proceedings of the 2020 ASEE Virtual Annual Conference Content Access*, Online, 2020, doi: 10.18260/1-2—35544.

[7] N. Stites *et al.*, "Analyzing an abbreviated dynamics concept inventory and its role as an instrument for assessing emergent learning pedagogies," *ASEE Annual Conference and Exposition, Conference Proceedings*, June, 2016, doi: 10.18260/p.26242.

[8] H. M. Inglis and C. Sandrock, "Using the Dynamics Concept Inventory to assess teaching effectiveness," in *Proceedings of the 2nd Biennial Conference of the South African Society for Engineering Educations*, Cape Town, 2013, pp. 304-306.

[8] N. Fang, "Difficult concepts in engineering dynamics: Students' perceptions and educational implications," *International Journal of Engineering Education*, vol. 30, no. 5, pp. 1110–1119, 2014.

[9] J. L. Davis, A. Baisley, G. Recktenwald, B. P. Self, and P. Cornwell, "A Modified Concept Inventory for Dynamics," in *Proceedings of the 2024 ASEE Annual Conference & Exposition*, 2024, Portland, Oregon. 10.18260/1-2—46457.

[10] M. Clayton, "Delphi: A technique to harness expert opinion for critical decision-making tasks in education," *Educational Psychology*, 17, 1997, pp. 373–386.

[11] N. Jorion, B. D. Gane, L. V. DiBello, and J. W. Pellegrino, "Developing and Validating a Concept Inventory," in *Proceedings of the 2015 ASEE Annual Conference*, 2015.

[12] M. Rodriguez, “Three Options are Optimal for Multiple-Choice Items: A Meta-analysis of 80 Years of Research,” *Educational Measurement: Issues and Practice*, vol. 24, no. 2, pp. 3-13, 2005.

[13] N. Jorian *et al*., “An Analytic Framework for Evaluating the Validity of Concept Inventory Claims,” *Journal of Engineering Education*, vol. 104, no. 4, pp. 454-496, 2015