A Review of Four Concept Inventories on Statics: Content, Psychometric Characteristics, and Application

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Abstract

A concept inventory is an assessment tool designed to evaluate the conceptual understanding of a subject. It quantifies a student's grasp of concepts, thereby assisting in identifying common errors, misconceptions, bottlenecks, and gaps in student learning, teaching strategies, or interventions. Statics serves as a foundational course for students in mechanical, civil, and aerospace engineering, covering topics, such as forces, moments, stresses, strains, trusses, free-body diagrams, and basic kinematics. The objective of this study was to collect, analyze, and review existing concept inventories in the literature pertaining to engineering Statics courses. We identified 21 concept inventories focused on the assessment of Statics concepts through the initial ASEE PEER conference paper repository and Google Scholar searches for Statics research. Four of these inventories were specifically geared towards Statics course topics and had been utilized in research, making them the target concept inventories for this study. We developed matrices to evaluate the concept inventories based on specific topics covered, referencing well-known Statics textbooks, and examined their psychometric characteristics, including validity and reliability evidence, along with their applications in the literature, such as citations and usage in research. Our findings indicate that due to the wide topic coverage and general use case of the Concept Assessment Tool for Statics, it remains the most cited and utilized concept inventory. The other concept inventories have been developed more recently, with the Test of Representational Competence with Vectors emerging as a reliable intervention assessment tool. This study aims to support engineering educators and researchers in identifying which concept inventories are most suitable under various conditions.

I. Introduction

Concept inventories are assessment tools grounded in research designed to examine students' comprehension of specific concepts [1]. They are often used to assess common errors, misconceptions, or bottlenecks in understanding, as well as to evaluate course content coverage, teaching strategies, or research interventions. Concept inventory use cases and topical coverage vary across trials and iterations, and separate instruments normally do not cover the same objectives, topics, and outcomes. A concept inventory can be made for a specific purpose, use case, group, or topic with specific classroom levels, subjects, target concepts, and applications in mind, as shown in Sangam and Jesiek's [22] comparative reviews of concept inventories in the context of circuits.

The oldest known Statics-related inventory is the Force Concept Inventory (FCI) [2]. Its literature describes how concept inventories can be used to quantify the state or level of students' conceptual understanding, which helps to determine what students are learning. This inventory was developed to monitor students' understanding of force and related kinematics. Of course, the FCI's uses were not limited to Statics courses, as concepts of force are not exclusive to the course, but also inclusive of other physics and dynamics courses. However, the applicability of the physics concepts it addressed to common Statics topics made it an appealing tool for research.

Statics is a course present in many engineering curricula, but perhaps most notably in mechanical and civil engineering [3]. This overlap is not exclusive to modern education; the standard of pre-requisite courses laying the foundation for what is to come, and the presence therein of classical mechanics, was present well before modern standards were established [4, 5]. Skills such as spatial reasoning needed to be developed and assessed before students could move on to more in-depth courses [6]. Engineering Statics – encompassed in courses such as Statics, Basic Mechanics, Statics and Dynamics, Mechanics of Materials, Structural Elements and Loading, and other varied names unique to their universities – continues to serve in this prerequisite role. The main competence developed in the course, as described by the Encyclopedia Brittanica [7], provides students with the analytical and graphical procedures needed to identify, describe, and assess the unknown forces and stresses acting on stationary objects. It provides a strong foundation in a simple context, upon which latter courses may build.

Statics is a major steppingstone for many engineering curricula, as highlighted by the topics covered and how commonplace they are across the later courses [8, 9]. Engineering Statics is a known example of a gateway course – foundational courses required by their respective programs, courses that often demonstrate high enrollment and a high risk of failure [8]. This combination of great importance and high stakes makes research of gateway courses a priority, and high enrollment creates opportunities for more and larger samples for course intervention research in comparison to other courses [9, 10]. This has led to other concept inventories being developed, some overtaking the FCI in specificity and utility to the field of mechanics (e.g., the Dynamics Concept Inventory (DCI)) [11, 12].

Concept inventories are also developed with the intent of standardizing student assessment and increasing the equality of evaluations, as was the case for Wage et al. [13]: "The signal processing community needs quantitative standardized tools to assess student learning in order to improve teaching methods and satisfy accreditation requirements" (pg. 448). The research-based and standardized approach to the creation and use of concept inventories allows for a valid, reliable, and consistent level of assessment difficulty across most student samples [14]. This is especially useful in ongoing research, such as evidenced in Davishahl and colleagues' publications [15, 16, 17, 18, 19, 20].

While there have been many published reviews on a given field's or subject's concept inventories (e.g., [21, 22]) we could not find a systematic review of concept inventories used in Engineering Statics education and research. As this is one of our areas of interest, we aim to address this gap in the literature for future instruction and research.

A. Purpose of Study

This study reviewed literature for concept inventories used in Statics education research, used by educators for evaluation of Statics courses, or developed specifically for use in Engineering Statics courses. This study focuses on concept inventories with a majority content covering topics directly related to Statics – while other concept inventories have been used in such research, or have historical relevance for Statics education, they were not reviewed as deeply. The research questions guiding this study were: (a) What concept inventories have been developed for Engineering Statics education?; (b) What content/topics in Engineering Statics are addressed in those concept inventories?; (c) What are the psychometric characteristics of each concept inventory?; and (d) To what extent did those concept inventories contribute to research on Statics education?

II. Literature Review

A. The Role of Reviews

Systematic reviews, as an approach to research inquiry, grew out of the need for an organized and critical summary of existing research in various fields of study. This was especially prevalent in the medical field, wherein, "the worldwide Cochrane Collaboration was formed in 1992 to provide an expanding resource of updateable systematic reviews" ([23], p. 92). Such reviews have gone on to provide objective summaries of diverse information in the healthcare fields, but also far beyond; highlighting gaps, successes, and points of note throughout available literature [24].

Reviews of concept inventories have been completed before. Reed-Rhoads and Imbrie [25] provided a review of 21 different courses' concept inventories, and reported the most prevalent respective concept inventories according to their findings. There are also reviews targeting individual inventories, often completed by the author of that same inventory as an approach to evaluating their own work. An example of this is Dr. Steif and colleagues' own reviews of the Concept Assessment Test for Statics (CATS) [26, 27]. These individual reviews provide further insight into the authors' thought process behind the development (and perhaps, revision) of their concept inventories, and commentary on the instrument's use or performance. Davishahl's work on the Test of Representational Competence with Vectors (TRCV) exemplifies this approach through its evolution with each year's review [15, 16, 17, 18, 19, 20].

B. Statics Topics

The topic categorization covered in this review was synthesized from multiple university syllabi and a well-known Statics textbook [28]. This includes topics that would be classically included in Statics (e.g., static equilibrium), as well as topics that are frequently combined into Statics courses but may apply to topic areas. Table 1 lists the topic categories and subcategories.

Table 1. Statics Content Categorized by Topics and Subtopics

#	Topic	Subtopics
1	Static Equilibrium	Static Equilibrium, Newton's Laws
2	Force Vectors	Vector Definitions, Coordinate Systems, Vector Components, Vector Algebra, Unit Vectors
3	Resolution of Forces	Concurrent Coplanar Forces, Collinear forces, Resultant Forces, Moments of Forces, Force Couples
4	Free-Body Analysis	Free-Body Diagrams, Equilibrium Analysis of a Particle (1-D Equilibrium), Equilibrium Analysis of Rigid Bodies (2-D and 3-D Equilibrium)

5	Types of Loading and Supports	Types of Supports, Concentrated/Point Loads, Distributed Loads, Special Topics in Force (e.g., Friction, Hydrostatic Loads),
6	Beams and Bending	Bending Moment (and Variations), Beam Analysis, Graphical Methods
7	Analysis of Multi-member Structures	Joint Analysis, Interaction Forces, Zero-, Two-, and Multi-force Members, Method of Sections, Trusses, Frames, Machines
8	Direct Stress	Tensile Stress, Compressive Stress, Shear Stress, Combined Stress
9	Strain	Strain, Elasticity, Factor of Safety, Design Stress
10	Loading Systems	Applied Loads, Principle of Superposition, Effects of Loading
11	Structural Elements	Structural Elements, Center of Gravity/Centroids, Moment of Inertia

III. Method

Cochrane's [29] review guide helped to define the process and structure of our review. The literature and inventory data were collected and allocated using a set inclusion and exclusion criteria defined (and detailed below) using the help of Cochrane's [29] instructions. The data were then compiled into a comprehensive set, summarized, and discussed.

Concept inventories were examined and coded according to their Statics content coverage, the ease and method of their acquisition, their defined purpose, their proposed use cases, their published psychometric analyses, and their cited use in literature. Outliers and exclusions were discussed briefly for their historical significance, their relation to Statics, or their influence on other concept inventories and the landscape of Engineering Statics research. Psychometric characteristics were documented using publicly available data on each respective concept inventory regardless of revision, such as evidence of validity, reliability, item correlation, item difficulty, and item discrimination. This information could help educators determine if the assessment is worth considering for use in their own classes.

A. Searching Strategies

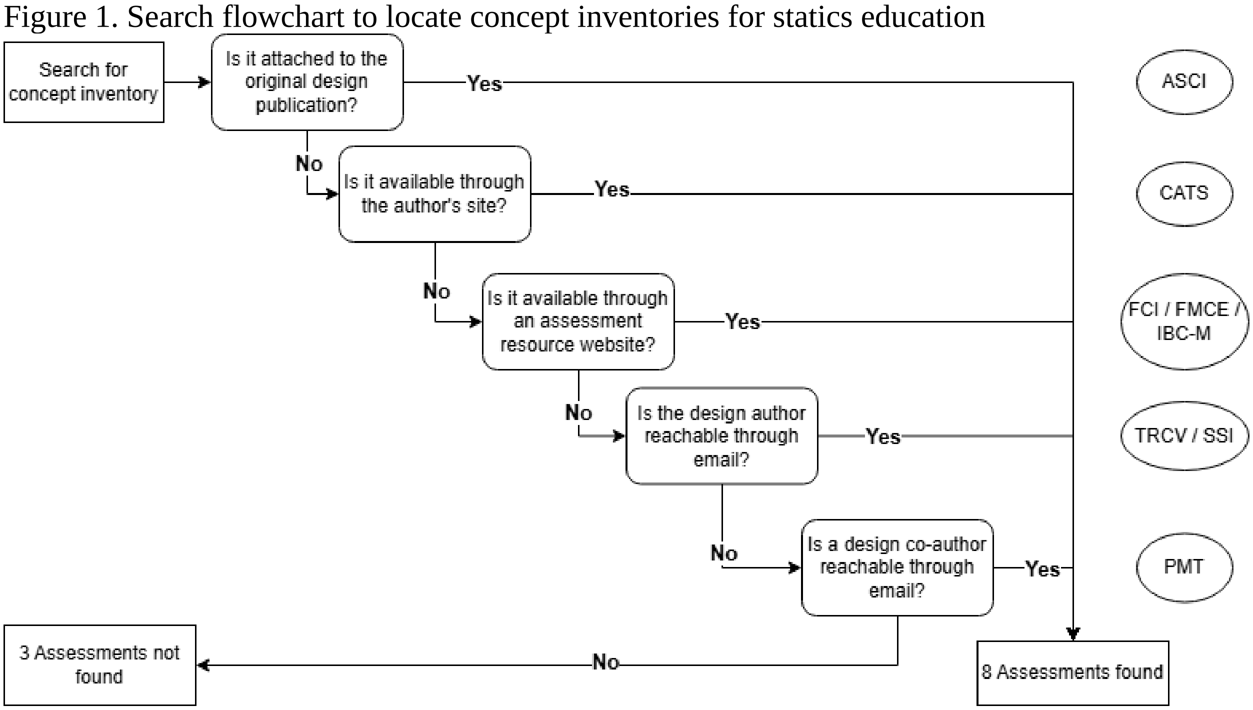
Our initial list of concept inventories was compiled from data found by Awartani et al. [9] for their study of educational interventions in Engineering Statics. The variety of concept inventories used in Statics-based intervention research gave immediate insight into instruments we could investigate, and how they had been utilized in the research space. Once literature on those concept inventories was found, reverse snowballing helped to find previous versions of those instruments, as well as other inventories that were used for research or as references. We also searched aggregator sites that house links to concept inventories, such as Hamburg University of Technology's Concept Warehouse site, which has unfortunately become inaccessible and unsearchable as of late 2024. Finally, we searched for concept inventories on ASEE Peer, Google Scholar, and the ProQuest Dissertations and Theses Global database. Table 2 shows our initial list of candidate inventories prior to any exclusions.

Once the search was complete, we then sought to acquire each concept inventory, following the steps represented in Figure 1. Some concept inventories (such as the FCI and IBC-M) were easy to acquire from aggregator sites such as Physport for free. Others required communication with the author's team to gain access such as CATS. These differentiated modes of access caused some complications in our process, as reaching out to authors does not guarantee a response, and those responses we received did not always come from the authors themselves. We make note of some of these accessibility challenges in our later discussion. Some concept inventories could not be found, or were only partially accessible, and thus had to be excluded from the review. Initial exclusions were STMA, CCMI, and MAT. This cut down our search to the 9 concept inventories papers in Table 3.

Table 2. Initial Search Results for Statics-Related Concept Inventories Ordered by Initial Year

#	Concept Inventories or Tests for Statics	Acronym	Authors
1	Stenquist Test of Mechanical Aptitude	STMA	Stenquist [30]
2	Force Concept Inventory	FCI	Hestenes et al. [2]
3	Force and Motion Conceptual Evaluation	FMCE	Thornton & Sokoloff [31]
4	Statics Skills Inventory	SSI	Danielson & Mehta [32]
5	Concept Assessment Tool for Statics (formerly, Statics Concept Inventory)	CATS (SCI)	Steif [33]
6	Inventory of Basic Conceptions - Mechanics	IBC-M	Halloun [34]
7	Alternate Statics Concept Inventory	ASCI	Papadopoulos et al. [35]
8	Physical Manipulative Tools	PMT	Walsh et al. [36]
9	Colorado Classical Mechanics Inventory (CCMI)	CCMI	Caballero et al. [37]
10	Test of Representational Competence with Vectors	TRCV	Davishahl et al. [17]
11	Mechanical Aptitude Test (MAT)	MAT	Bairaktarova & Reeping [38]

Figure 1. Search flowchart to locate concept inventories for statics education



B. Inclusion and Exclusion Criteria

Using the topics listed in Table 1, two authors of this study with mechanical engineering experience coded the items within each inventory according to topic coverage. To align with the purpose of the current study, the authors decided to focus on those concept inventories that exhibited an explicit focus on Statics content, determined by at least 70% of an inventory's items being directly applicable to Engineering Statics. As one common example, questions dealing with acceleration were not considered applicable to this review, as Statics is concerned with physical systems that have no net-acceleration [28]. We also focused on the latest complete version of each inventory found during our analysis, only referring to earlier versions in two cases: When important information such as psychometric data were solely available for those versions, or when assessing the use of that inventory through its various literary citations excluding of self-citations.

IV. Results

Table 3. Topic Coverage of the Concept Inventories Relevant to Statics

		FCI		**FMCE**		**SSI**		**CATS**		**IBCM**		**ASCI**		**PMT**		**TRCV**	
#	Topic	#Q	%	#Q	%	#Q	%	#Q	%	#Q	%	#Q	%	#Q	%	#Q	%
1	Static Equilibrium	9	30	7	15					4	12	2	20	4	9		
2	Force Vectors	2	7			3	25			5	15					14	88
3	Resolution of Forces	3	10	2	4	1	8	3	11	1	3	4	40			2	13
4	Free-Body Analysis	2				5	42	6	22	2	6	2	20	1	2		
5	Types of Loading and Supports					2	17	15	56			1	10				
6	Beams and Bending																
7	Analysis of Multi-Member Structures					1	8	3	11			1	10				
8	Direct Stress																
9	Strain																
10	Loading Systems																
11	Structural Elements													3	7		
12	# of Statics Relevant Qs	16	53	9	19	12	100	27	100	11	36	10	100	8	18	16	10
13	# of Irrelevant Qs	14	47	38	81	0	0	0	0	22	64	10	0	36	82	0	0

Note. Q = Questions; #Q = Number of topic-related questions; % = Percentage of questions out of total content

A. Contents of Concept Inventories on Statics Categorized by Topic

Compiled data on the content coverage of our collected inventories is shown in Table 3. Table 3 acts as a topics matrix representing the topics covered by individual items. This data was also used to determine what percentage of each instrument was relevant to Engineering Statics (see rows 12 and 13). Four concept inventories showed a clear alignment with Statics content – SSI, CATS, ASCI, and TRCV. All four were coded with a complete 100% score on the Statics topics matrix; and yet each focused on a different set of topics, implying there may be differences in each instrument's priorities and subsequent use cases.

B. Psychometric Characteristics of Concept Inventories on Statics

Many concept inventories have a study of origin, or set thereof, that discuss the initial development and testing of those instruments. While much of this work discusses the concepts (and misconceptions) being assessed, it also includes psychometric information. Validity, reliability, item difficulty, and item discrimination evidence not only help provide a consistent tool for characteristic measurements but also help to weigh how accurately the instrument represents the data it is designed to measure. This data is compiled in Table 4.

Table 4. Psychometric Characteristics of Concept Inventories on Statics

Concept Inventory	Reliability	Content Validity	Construct Validity	Convergent Validity	Criterion Validity	Item Difficulty	Item Discrimination
Statics Skills Inventory	-	[39]; [40]; [41]	-	[39]	-	[39]	[39]
Concept Assessment Tool for Statics (CATS)	Cronbach α = 0.89. [42]; Test-retest reliability r [43]	[25]	[25]; [44]	-	[25]; [26]	[25]; [44]	[25]; [44]
Alternate Statics Concept Inventory (ASCI)	-	[35]	-	-	-	[35]	[35]
Test of Repre-sentational Competence with Vectors (TRCV)	Implied test-retest reliability [15, 16, 17, 18, 19, 20]	-	-	[15]; [17]; [20]	[17]; [20]	[15]	[15]

C. Applications of Concept Inventories on Statics in the Literature

Our exploration of the applications and use cases for concept inventories comprised searching available documentation, guidance from online repositories, extant examples in literature, and words from inventory developers. To explore the usage of each inventory in literature, a search was last conducted using Google Scholar in April of 2025, targeting the four concept inventories.

Each concept inventory was searched using a combination of keywords to find as many results as possible. Variations of these keywords included:

- "inventory name"
- "author's name" + "Statics" + inventory name
- "Statics" + inventory name
- "Statics" + "inventory abbreviation"

Table 5. Usability sheet of review inventories

Category	**SSI**	**CATS**	**ASCI**	**TRCV**
Level	Second year	Second year	Second year	First or second year
Means of Acquisition	E-mail: Reached out to Dr. Danielson	Website: https://engineering-education.com/	Attached to source [35]	Website: https://conceptwarehouse.tufts.edu
Cost	Free	Free	Free	Free
Directions for Administrators	Yes	Yes	No	Yes
Answer Key	No	Yes	Yes	Yes
Duration	No	50-60 minutes	No	No
Pre-Assessment	Not advised	Not advised	Yes	Yes
Post Assessment	Yes	Yes	No	Yes
No. of Questions	12 questions	27 questions	10 questions	16 questions
Question Types	Written answers	Multiple choice	Multiple choice	Multiple choice
Number of Choices	N/A	5	4	4
Notes on Acquisition	Access link is not available, but author is reachable [39]	Free through website with author's approval	Free via ASEE Peer, through Concept Warehouse, or by emailing the author	Free through Concept Warehouse or by emailing the author

Table 5 summarizes the search results of the four included concept inventories acquired for this review. A few things of note in this table: It is apparent that due to their focus on Statics, they are all aimed at early second-year students, but TRCV is cited to be appropriate for first-year students as well. CATS is also the only inventory with a suggested exam duration. The remaining characteristics will be discussed later in this review.

Table 6 covers the citation matrix of each inventory included. The results were filtered through and divided into two citation cases: Mentions, and Applications. Mentions simply mentioned, reviewed, or discussed the inventory in question, while Applications used the inventory in education or research involving students. Self-citations by the authors testing the development of their concept inventories were excluded from the count. SSI has the second-highest use rate. CATS is the most cited concept inventory for Statics by a wide margin, and its total catalogued citations could have gone beyond the 95 listed here given additional time. ASCI has the second-highest number of search results, but that number may be inflated due to an overlap in its acronym with the SCI (an earlier version of CATS). TRCV and ASCI tie for third place in terms of total citations.

Table 6. Concept inventory uses and search results on Google Scholar as of April 21st, 2025

	SSI	CATS	ASCI	TRCV
Mentions	10	75	5	4
Applications	3	20	0	1
Total Citations	13	95*	5	5
Maximum Search Results	96	674	158	45

**There are too many results to properly count in time*

V. Discussion

This section discusses notable highlights in our findings, a brief look into the development, use, and history of the inventories selected, and connections to historically significant concept inventories found during review.

A. Concept Inventories of Interest and Their Statics Topic Coverage

Statics Skill Inventory (Danielson & Mehta, 2000)

The SSI is unique in its assessment of student ability in the *application* of concepts, rather than strictly assessing student understanding. The purpose of this inventory is to focus on the skills and steps necessary for applying conceptual understanding in Statics. The SSI went through many iterations and variations in its question pool from 2000 up to 2008 [32, 39, 40, 41], when more thorough testing provides us with more data and greater evidence of validity. Over time, it focused down from assessing a range of 53 skills to 12 [39], and now demonstrates a more nuanced evaluation of those skills through its written response problems when compared to a multiple-choice assessment. The lead author of the inventory, Dr. Danielson, was particularly complimentary of Dr. Steif's (see CATS) work during these iterations, and the authors may have commented on each other's work and their development processes occurred around the same time [40]. The Statics skills ranking provided included in the 2008 [39] paper could be particularly useful for researchers attempting to create their own Statics concept inventories, regardless of what topics they wish to cover.

Sadly, according to Dr. Danielson, the inventory itself has not been published nor archived in its full and official format. While the 2008 [39] paper provided an accounting of the skills and topics covered, the assessment objectives, the outcomes, and enough application and administration data to validate its use, there is no official method for obtaining the inventory. This study's research team obtained a copy along with a draft for an incomplete secondary version by reaching out to Dr. Danielson himself. According to one of the concept inventory's authors, the reasoning to not have archived it was in part due to the popularity, availability, and immediate use of CATS. The author claimed they considered one Statics concept inventory to be enough for public use.

Despite the current state of the assessment, there are still years of work published on the inventory's development and use. While we cannot be certain about the future availability of the SSI, we would certainly argue that the market of concept inventories does not need to be limited to one popular assessment. We believe the concept inventory landscape can benefit from more options for researchers and educators, especially given the SSI's differentiated topic coverage and written assessments.

Concept Assessment Tool for Statics (Formerly, Statics Concept Inventory) (Steif, 2003)

Due to confusion about its original name, Statics Concept Inventory [42], and its acronym (SCI) which overlapped with a similar concept inventory, the inventory name was changed to CATS. According to Jorion et al. [44] that analyzed the validity and reliability evidence using the classical test theory and item response theory, CATS is a reasonable concept inventory to use for the purpose of a low-stakes assessment of the concepts it is meant to assess.

CATS is currently the most cited and utilized Statics-focused concept inventory available, as shown in Table 6. It is the result of a collaboration between many researchers, some of whom would go on to develop their own concept inventories, (e.g., Dr. Scott Danielson). As mentioned before, it was one of the first Statics concept inventories to be published, first appearing in 2003. It was also the first inventory on the list to have had its own website https://engineering-education.com/index.php where readers can find more direct access to the psychometric data, citations, and other important details that researchers and instructors could benefit from.

While its use, administration, analysis, and practices have evolved regularly [45], CATS is not without its shortcomings. Papadopoulos et al. [35], for example, discussed that CATS may not be ideal as a pre-assessment tool due to the topics being more focused on the midterm period of the course. Dr. Steif, the primary author, seems aware of this, "While the SCI [CATS] effectively captures important aspects of students' statics conceptual knowledge at the end of a statics course, this does not imply that the SCI is the best measure of relevant incoming knowledge, especially when one's goal is to assess the effectiveness of instruction." ([46], p. 1). Jorion et al. [44] also highlighted how it cannot be used for an in-depth analysis of student skills relating to the topics covered because it was not designed for that purpose. CATS touches base with four topic categories, but it does not provide any deeper assessment of their subcategories. However, its ease of access, ease of use, evidence of validity, and wider topic coverage make it a useful and popular assessment tool.

Alternate Statics Concept Inventory (Papadopoulos et al., 2016)

ASCI is the first official attempt after CATS to develop a new statics concept inventory. As stated earlier, Papadopoulos et al. [35] mentioned CATS positively, but criticized its use as a pre-assessment tool. Those same authors would then go on to develop, test, and publish the ASCI, whose purpose is to act as a pre-assessment tool for use alongside CATS or for Statics overall. While ASCI has not been widely used by other researchers, it is still publicly accessible with accompanying psychometric data through its 2016 publication. A subset of its questions was also made available on Concept Warehouse. In fact, the authors note that the ASCI does not need to be used all at once as a complete concept inventory. Deploying subsets of questions as targeted pre-assessments is a valid use case for the concept inventory's items. It is also an interesting case to many authors discussing the iterative and derivative nature of concept inventory design, such as Direnga [47]. She highlights and admires the subtle changes made to CATS to allow for an easier approach to this concept inventory as a pre-assessment. Will Pinto [48] also mentioned how it helps catch initial naive student misconceptions that CATS would normally missed.

Test of Representational Competence with Vectors (Davishahl et al., 2019)

According to its authors, the TRCV is intended to act as a physics and vector analysis concept inventory, but its coverage of vectors is largely undertaken in a Statics context. The questions focused on relating vectors and vector additions to static objects, often which integrating compatible concepts like moments, types of supports, and multi-member pin-jointed structures. This is an example of a concept inventory focused on a small subset of concepts within a larger curricular framework, assessing a narrow range of misconceptions specific to the vector-based modeling of static systems.

As can be seen in Davishahl et al. [17], TRCV coincides with a spatial visualization course intervention that was conducted year after year for Statics, and triangulated using the Mental Cutting Test (MCT) [49] and CATS data. The concept inventory, in the case of its development, was used to provide a reliable and consistent assessment tool between yearly datasets of test and control groups. Incidentally, Dr. Davishahl was quick to respond to our messages, and informed us about the Concept Warehouse as a resource by professors for professors to share their concept inventory design work and assessment items [50, 51].

B. Topic Coverage

Equilibrium-related topics are evidenced in a majority of items across all four Statics concept inventories. In addition, many questions use 2D equilibrium as a context through which to ask about other concepts – though it these questions, we tended to focus on the higher-order context being addressed, rather than the context in which it was portrayed. Table 3 also shows that all four instruments addressed "Resolution of Forces" to some varying degree. SSI's topic coverage is mostly centered around free-body diagrams, with varying inclusions of other topics in each question. CATS heavily favors questions that depend on the loading and support of static structures, which aligns with its intended evaluation of conceptual understanding in applied Statics contexts. ASCI's topic coverage leans more towards the earlier part of the course curriculum, which aligns with its goal of being a pre-assessment paired with CATS. ASCI also includes fewer questions that combine multiple topics within the same context. TRCV is unique in that it almost all falls within the vector analysis topics, barring two questions that stray into the territory of "Resolution of Forces".

As CATS is by far the most popular inventory, and served as a resource or inspiration for the other inventories listed, may be useful to draw comparisons between CATS and other instruments. The TRCV for example is more theoretical in its subject-matter, questions, and topics, contrasting with CATS's more application-oriented approach. While the generalizable understanding of mathematics assessed in the TRCV might be employed in CATS, CATS cannot assess those skills independent of other concepts unique to Statics itself. SSI and CATS complement each other's coverage of the core Statics subjects – if TRCV assessed general knowledge, and CATS embedded that knowledge in a Statics context, the SSI goes on to assess students understanding of *how* generalized knowledge can be used to analyze Static systems. This is even further complemented by ASCI's coverage of the earlier course topics. If an instructor was willing to compile the four concept inventories together, it could make for a thorough assessment of the course's fundamental concepts and their applications.

While direct stress, strain, loading systems, and structural elements are not directly questioned, they are presented as the context of a few problems in SSI and CATS. However, they did not represent the concepts being assessed – only the context for certain questions.

C. Validity and Reliability

According to Table 6, CATS has the widest validity and reliability evidence published by the original authors. SSI may seem minimal in validity evidence, but the team sizes and iteration work done using the Delphi process, as well as the yearly data provided by Dr. Danielson in each development publication, cannot be understated. It shows the rigor put into the project to continuously improve the concept inventory. ASCI, on the other hand, has little publicly available evidence for validity. It aims to build from the questions and topics shown in CATS and does, therefore, benefit from a content validity approach to assess whether it adequately covers those same topics - since CATS provided valid evidence for the same content coverage. The TRCV saw authors consistently providing new test data to improve their work for every version as a form of test-retest reliability. This was also used in a predictive nature to conduct criterion validity as well as plenty of convergent validity data using the Mental Cutting Test (MCT) and CATS data.

With that in mind, CATS was the only inventory reviewed to show results for reliability testing. The TRCV does conduct a test-retest show of reliability, but it does not highlight that the versions do change between certain datasets. Three out of the four concept inventories, SSI, CATS, and TRCV, used correlations as a form of convergent validity. It was also the most popular form of validation between different versions of the same inventory, such as with TRCV. These correlations were either compared against other concept inventories or previously used school exams for the course. The second most popular validity evidence was content validity.

D. Item Difficulty and Discrimination

All concept inventories have published evidence of item difficulty and discrimination indexes for at least one version of the assessment. Authors also clarified some of their difficulty indexes could be attributed to factors outside of the assessment's design, such as Davishahl et al. [15] using the TRCV to test the success of an intervention between a control and test group. In this case, TRCV itself is not the one seeing improvement as an assessment tool, but rather the scores seemed improved because of improved teaching methods introduced.

The item difficulty indexes presented cannot be compared directly. These inventories are meant to cover different topics using distinct processes, so their analysis results can only be presented on an individual basis. The scores presented are as follows: For SSI, the paper's test scoring is shown that the highest scoring difficulty index is item 4 at 0.70, with a maximum discrimination index item being a draw between six items at 0.67. It is not made clear why this is the case, but the paper mentions it could possibly be due to the sample students making the same basic errors across most items. Item 8 is the most difficult one tested, with an index of 0.04. For CATS, the highest score for a difficulty index is item 10 at approximately 0.86, and a maximum item discrimination index for item 4 at approximately 0.83. The most difficult item on the concept inventory is item 20, with an index of 0.31. For ASCI, the highest scoring difficulty index is a draw between items 8 and 9 at 0.53 in pre-assessment and item 2 in post-assessment at 0.77. The paper highlighted that a favorable result is the highest rate of item discrimination index being item 3 at 0.71. The most difficult item is shown to be item 5 in both pre- and post-assessments at 0.03 and 0.07, respectively.

TRCV comes with multiple tables showing multiple datasets at different times, different sample students, and different versions. For the sake of this section, we will use the analysis of version 2 in Winter 2019. This table features a maximum item difficulty index of 0.81 for item 2 and a point-biserial correlation display of the item discrimination maximum with item 3 at 0.58. The most difficult item is said to be item 10 at an index of 0.10. It should be noted that TRCV does list its items in its index analysis as a table of ten-item descriptions rather than showing the complete list of sixteen questions. Individual question analysis is not as clearly on display.

It can be interpreted from this that the item difficulty does not strictly determine the item discrimination and vice versa. This can also be applied to the concept inventory as a whole; a difficult concept inventory does not mean a good concept inventory. There is always the probability of an issue relating to how difficult certain concepts are to discriminate and determine student understanding, as is shown in the Delphi process iterations of SSI.

VI. Conclusion

Although more ten concept inventories were used for the purposes of Statics education research, only four were explored here due to their overt focus on Statics related concepts. In addition, there has been little *recent* development in the realm of Statics concept inventories, and past instruments have, at times, become more difficult to access. That said, with the ASCI and TRCV being easily accessible, and aggregator sites like Concept Warehouse being run independently, there could be a more varied selection of assessment tools to come in the near future. The work of Dr. Steif and his collaborators is broadly cited for good reason, but that does not mean other concept inventories should not be made available. Having a variety of concept inventories allows educators and researchers to assess specific topics (such as with TRCV), a specific set of course skills (such as with SSI), or to tailor assessment based on course progression (such as with ASCI). There are also topics not yet represented by the inventories used in literature, such as for companion topics from Mechanics of Materials (Stress, Strain, Hooke's Law, etc...) or other areas. Having distinct tools for various testing methods, objectives, and outcomes is likewise a priotity, as the use cases of the SSI and ASCI demonstrate the utility of having tested, validated assessments that function in fundamentally different ways. We hope this paper inspires further developments and encourages the use, and further diversification, of the concept inventories available for Engineering Statics.

Limitations of the Study

We would like to note that we could not find a definitive list of all Statics-related concept inventories, and were thus limited to currently available search engine capabilities and our own university library access. There may be publications, or even instruments, that we missed during our search. In addition, some of our sourcing for the concept inventories we identified relied entirely on human interaction – late responses, missed messages, and the inability to provide certain materials all plagued our ability to collect and analyze data. Finally, our interpretation of the conceptual nature and contexts for the items we reviewed is based on our own understandings, experiences, and assumptions. We do not know the intentions of the authors of those concept inventories beyond what was present in their prior publications. It is possible that our own misunderstandings or misconceptions could have influenced these results.

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