



# THE ASSESSMENT OF LEARNING IN ENGINEERING EDUCATION

**PRACTICE AND POLICY**

JOHN HEYWOOD

---

# **The Assessment of Learning in Engineering Education**

**Practice and Policy**

---

**John Heywood**

Trinity College, The University of Dublin

 **IEEE**  
IEEE PRESS

**WILEY**

---

Copyright © 2016 by The Institute of Electrical and Electronics Engineers, Inc.

Published by John Wiley & Sons, Inc., Hoboken, New Jersey. All rights reserved.

Published simultaneously in Canada.

No part of this publication may be reproduced, stored in a retrieval system, or transmitted in any form or by any means, electronic, mechanical, photocopying, recording, scanning, or otherwise, except as permitted under Section 107 or 108 of the 1976 United States Copyright Act, without either the prior written permission of the Publisher, or authorization through payment of the appropriate per-copy fee to the Copyright Clearance Center, Inc., 222 Rosewood Drive, Danvers, MA 01923, (978) 750-8400, fax (978) 750-4470, or on the web at [www.copyright.com](http://www.copyright.com). Requests to the Publisher for permission should be addressed to the Permissions Department, John Wiley & Sons, Inc., 111 River Street, Hoboken, NJ 07030, (201) 748-6011, fax (201) 748-6008, or online at <http://www.wiley.com/go/permission>.

**Limit of Liability/Disclaimer of Warranty:** While the publisher and author have used their best efforts in preparing this book, they make no representations or warranties with respect to the accuracy or completeness of the contents of this book and specifically disclaim any implied warranties of merchantability or fitness for a particular purpose. No warranty may be created or extended by sales representatives or written sales materials. The advice and strategies contained herein may not be suitable for your situation. You should consult with a professional where appropriate. Neither the publisher nor author shall be liable for any loss of profit or any other commercial damages, including but not limited to special, incidental, consequential, or other damages.

For general information on our other products and services or for technical support, please contact our Customer Care Department within the United States at (800) 762-2974, outside the United States at (317) 572-3993 or fax (317) 572-4002.

Wiley also publishes its books in a variety of electronic formats. Some content that appears in print may not be available in electronic formats. For more information about Wiley products, visit our web site at [www.wiley.com](http://www.wiley.com).

*Library of Congress Cataloging-in-Publication Data is available.*

ISBN: 978-1-119-17551-3

Printed in the United States of America.

10 9 8 7 6 5 4 3 2 1

*In Memory of*  
Georgine Loacker  
*Doyen of Assessment*

---

# Preface

---

The core idea explored in this book is that of judgment. Judgment is something that all professionals are called upon to do simply because of what it means to be a professional. This book explores specifically how we judge engineering education. A great deal of time and effort worldwide is being put into redesigning engineering courses and programs to meet the accreditation requirements of various agencies that judge whether degree programs are producing sufficiently qualified engineers. These agencies focus on assessment as the mechanism for evaluating courses and student learning, but because such assessment has far-reaching impact, it is appropriate to examine both the agencies and their methods. In this text, I try to, in a somewhat nonlinear fashion, explore what it means to claim to be “professional” in one’s role as a teacher. Beyond content knowledge and understanding, theories of learning, professionalism includes a defensible theory and philosophy of assessment for one role of a teacher is to judge student progress. The aim of the text is, therefore, to provide sufficient data for an engineering educator to acquire a defensible theory or philosophy of assessment.

Assessment is not a stand-alone topic best left to experts. Examining assessment is one way of focusing on the curriculum for it cannot be divorced from learning, instruction, and content. It is integral to the curriculum process yet, more often than not, it is the afterthought of the educational process. Focusing on assessment forces us to consider in detail the aims and objectives of programs and for whom they serve. This book focuses internally on the problems of the curricula we have, and externally on the dictates of the sociotechnical system in which we live; these are inextricably linked. The book brings into sharp relief the relative responsibilities of academia and industry for the development of their charges as professionals.

This book is not about particular techniques of measurement or a “how to” guide for instructors. These can be found in most books on assessment in higher education (Angelo and Cross, 1994; Heywood, 2000). Rather this book is about the validity of teaching and judging learning and therefore includes illustrations of what our colleagues are doing framed against the backdrop of accepted educational policies.

The late Sister Georgine Loacker, Professor of English at Alverno College and Chairperson of the College’s Assessment Council to whom this book is dedicated and I disagreed about many things but we did not disagree about the principles of assessment. She and her colleagues defined *assessment* as “a multidimensional attempt to observe and, on the basis of criteria, to judge the individual learner in action” that is the position

taken in this book. In the case of professional students, it means judging them in *both* academic and workplace situations.

“To undertake assessment means sampling, observing, and judging according to criteria. It means developing a whole array of techniques to take into account the fullest possible range of human talents. And it means an ongoing commitment to dealing with these kinds of questions” (Alverno College, 1994). This book is about how the engineering community has and is answering these questions and how it has and is determining the criteria on which such judgments are made. In sum, it is about practice and how research and theory should inform practice and policy.

Readers may come at this from different perspectives. Administrators and policy makers may be more concerned with assessment and its role in accountability, whereas instructors may be concerned with the impact that assessment has on learning. Similarly, the focus of the former will be, in all probability, on the curriculum, whereas the latter are likely to be more focused on techniques. Here it is argued that the two are not separable from each other. The more one tries to separate them, the more one becomes misled because they become detached from the system of which they are a part. This book is an attempt to demonstrate that this is the case and frame assessment more holistically.

John Heywood

## References

- Angelo, T., and Cross, K. P. (1994). *Classroom Assessment Techniques*. San Francisco: Jossey-Bass.
- Alverno College. (1994). *Student-Assessment-as-Learning at Alverno College*. Milwaukee, WI: Alverno College Institute.
- Heywood, J. (2000). *Assessment in Higher Education. Student Learning, Teaching Programmes and Institutions*. London: Jessica Kingsley.

---

# Acknowledgments

---

This book resulted from a request by Marcia Mentkowski to write a short commentary on developments in performance-based assessment in engineering education. Bill Williams encouraged me to develop the drafts into a book and Rich Felder provided valuable criticism. During the subsequent development, Bill, together with Mani Mina and Alan Cheville, spent many hours critiquing the text. Russ Korte drew my attention to important papers that had escaped my search. I am most grateful to them for their kindness and their no-holds-barred support. Meriel Huggard has helped me get the text ship-shape for which I am also most grateful.

A book of this kind is the result of many influences. Sir Charles Carter triggered my interest in assessment when, 50 years ago, he offered me a Leverhulme Senior Research Fellowship to investigate examining in universities. The work undertaken for this fellowship led the late Harry Edels to invite me to assist him and his colleagues in the development of a new university entrance examination in engineering science for the Joint Matriculation Board. The development of this examination resulted in a 20-year collaboration with the late Deryk Kelly. We were supported by George Carter and Glyn Price. It should be noted that the Board, supported by its Secretary Mr. R. Christopher and later Mr. C. Vickerman, departed from its usual organizational practices and provided a structure that enabled this unique curriculum development. Later, in Ireland, in collaboration with Seamus McGuinness and the late Denstone Murphy, we attempted to apply the model developed for engineering science to school examinations in history and mathematics.

During this period, Michael Youngman, Bob Oxtoby, the late Denis Monk, and I responded to the criticism that university and school curricular in engineering did not respond to what engineers actually do by undertaking a job analysis of what engineers actually did using a statistical methodology developed by Youngman. I was also invited to undertake other collaborations and investigations in industry by the late Bill Humble and the late Barry Turner. Throughout the last 30 years, I have had valuable discussions with John Cowan about assessment.

After my first book on assessment in higher education was published, Georgine Loacker contacted me and the developments at Alverno College came into my thinking. I hope that to use the title of their book that this contribution will provide "Learning That Lasts."

Taken together, these studies provided the setting for the development of this book and those I have mentioned undoubtedly influenced the direction that my thoughts on

assessment have taken as did Alec Martin and Lester Parker. To these should be added James Freeman, who introduced me to research on assessment in medical education and showed me its bearing on engineering education, and to Catherine Griffin, my doctoral student, who undertook a longitudinal study of portfolio assessment among nurses with whom I had many mind-stretching discussions. To all whom I have mentioned—Thank You.

Finally, no acknowledgment would be complete without a thank you to all the authors whose work I have read, and whose contributions gave me so much pleasure. I regret that the scale of the exercise prevented me from drawing attention to many other studies that merited attention.



---

# Contents

---

Preface, xiii

Acknowledgments, xv

<b>1</b>	<b>Prologue</b>	<b>1</b>
1.1	General Introduction: The Functions of Assessment,	1
1.2	Health Warning: Ambiguities in the Use of the Term “Assessment”,	6
1.3	The Assessment of Persons for the Professions,	8
1.4	The Engineering Profession,	10
1.5	The Development of Higher and Engineering Education as Areas of Academic Study in the 1960s,	12
1.6	Assumptions About Examinations: Reliability,	12
1.7	Myths Surrounding Examinations,	14
1.8	The Introduction of Coursework Assessment,	17
1.9	Rethinking Validity,	19
1.10	Wastage (Dropout): The Predictive Value of School Examinations for Satisfactory Performance in Higher Education,	20
1.11	Factors Influencing Performance in College Courses,	22
1.12	Assessment: Results and Accountability,	25
1.13	Assessing the Learner,	26
	Notes,	27
	References,	27
<b>2</b>	<b>Assessment and the Preparation of Engineers for Work</b>	<b>35</b>
2.1	Engineers at Work,	36
2.2	An Alternative Approach to the Education and Training of Engineers for Industry,	37
2.3	Toward an Alternative Curriculum for Engineering,	42
2.4	Creativity in Engineering and Design,	43
2.5	Furneaux’s Study of a University’s Examinations in First-Year Mechanical Engineering: The Argument for “Objectives”,	48
2.6	Discussion,	51

Notes, 53  
References, 54

<b>3</b>	<b>The Development of a Multiple-Objective (Strategy) Examination and Multidimensional Assessment and Evaluation</b>	<b>61</b>
3.1	The Development of an Advanced Level Examination in Engineering Science (For 17/18-Year-Old High School Students): The Assessment of Achievement and Competency, 62	
3.2	Skills Involved in Writing Design Proposals and Practical Laboratory Work, 72	
3.3	A Balanced System of Assessment, 74	
3.4	Pictures of the Curriculum Process, 75	
3.5	Multidimensional Assessment and Evaluation: A Case Study, 79	
3.6	Discussion, 83	
	Notes, 84	
	References, 85	
<b>4</b>	<b>Categorizing the Work Done by Engineers: Implications for Assessment and Training</b>	<b>89</b>
4.1	Introduction, 90	
4.2	A Study of Engineers at Work in a Firm in the Aircraft Industry, 91	
4.3	The Application of <i>The Taxonomy of Educational Objectives</i> to the Task Analysis of Managers in a Steel Plant, 96	
4.4	The Significance of Interpersonal Competence, 96	
4.5	A Comparative Study of British and German Production Engineers (Managers), 101	
4.6	Engineering Knowledge, 103	
4.7	Discussion, 105	
	Notes, 105	
	References, 107	
<b>5</b>	<b>Competency-Based Qualifications in the United Kingdom and United States and Other Developments</b>	<b>111</b>
5.1	The Development of Competency-Based Vocational Qualifications in the United Kingdom, 112	
5.2	Outcomes Approaches in High Schools in the United Kingdom, 115	
5.3	Standards in Schools in the United States, 116	
5.4	Education for Capability: Capability vs. Competence, 117	
5.5	Ability (Assessment)-Led Curricula: The Alverno College Model, 119	
5.6	The Enterprise in Higher Education Initiative in the United Kingdom and the SCANS Report in the United States, 122	

5.7	The College Outcome Measures Program, 125	
5.8	Discussion, 127	
	Notes, 130	
	References, 130	
<b>6</b>	<b>The Impact of Accreditation</b>	<b>133</b>
6.1	ABET, European Higher Education Area (Bologna Process), and the Regulation of the Curriculum, 134	
6.2	Taxonomies, 135	
6.3	Outcomes-Based Engineering Education, 142	
6.4	Mastery Learning and Personalized Systems of Instruction, 147	
6.5	Discussion, 152	
	References, 152	
<b>7</b>	<b>Student Variability: The Individual, the Organization, and Evaluation</b>	<b>157</b>
7.1	Introduction, 158	
7.2	Learning and Teaching Styles, 161	
7.3	Study Habits/Strategies, 163	
7.4	Intellectual Development, 165	
7.5	Critical Thinking, 168	
7.6	The Assessment of Development, 172	
7.7	The Reflective Practitioner, 174	
7.8	Adaptive Expertise, 180	
7.9	Discussion, 181	
	Notes, 182	
	References, 183	
<b>8</b>	<b>Emotional Intelligence, Peer and Self-Assessment, Journals and Portfolios, and Learning-How-to-Learn</b>	<b>189</b>
8.1	Introduction, 190	
8.2	Emotional Intelligence, 191	
8.3	Self- and Peer Assessment, 193	
8.4	Learning Journals and Portfolios, 206	
8.5	Learning-How-to-Learn, 209	
8.6	Discussion, 210	
	Note, 211	
	References, 211	
<b>9</b>	<b>Experiential Learning, Interdisciplinarity, Projects, and Teamwork</b>	<b>217</b>
9.1	Introduction, 218	
9.2	Project Work as a Vehicle for Integrated Learning and Interdisciplinarity, 219	

- 9.3 Learning to Collaborate, 220
- 9.4 Constructive Controversy, 224
- 9.5 Communication, Teamwork, and Collegial Impediments to the Development of Good Engineering Practice, 225
- 9.6 The Demand for Skill in Innovation: Can It Be Taught?, 227
- 9.7 Creativity, Teamwork, and Reflective Practice (See Also Section 2.4), 228
- 9.8 Can Teamwork Be Taught?, 229
- 9.9 Discussion, 235
- References, 236

## **10 Competencies 241**

- 10.1 Introduction, 242
- 10.2 The Iowa Studies (ISU), 244
- 10.3 The Outcomes Approach in Australia, Europe, and Elsewhere, 246
- 10.4 The CDIO Initiative, 247
- 10.5 A Standards-Based Approach to the Curriculum, 248
- 10.6 Recent European Studies, 252
- 10.7 Impact of Subjects (Courses) on Person-Centered Interventions, 255
- 10.8 The Potential for Comparative Studies: Choosing Competencies, 256
- 10.9 Expressive Outcomes, 258
- 10.10 Discussion, 259
- References, 260

## **11 “Outside” Competency 265**

- 11.1 Introduction, 266
- 11.2 Accidental Competencies, 267
- 11.3 Understanding Competence at Work, 269
- 11.4 Contextual Competence, 270
- 11.5 A Post-Technician Cooperative Apprenticeship, 272
- 11.6 Theories of Competence Development in Adult Life, 275
- 11.7 Discussion, 278
- Notes, 279
- References, 280

## **12 Assessment, Moral Purpose, and Social Responsibility 283**

- 12.1 Introduction, 283
- 12.2 Moral Purpose and the Power of Grading, 284
- 12.3 From Reliability to Validity: Toward a Philosophy of Engineering Education, 284
- 12.4 Screening the Aims of Engineering Education, 285

- 12.5 The Role of Educational Institutions in the Preparation for Industry (the Development of Professional Skills), 287
- 12.6 The Role of Industry in Professional Development, 289
- 12.7 Assessment and the Curriculum, 290
- 12.8 Changing Patterns in the Workforce, the Structure of Higher Education, 291
- 12.9 Lifelong Education and Credentialing, 293
- 12.10 Conclusion, 295
- Notes, 297
- References, 298

**A A Quick Guide to the Changing Terminology in the Area of "Assessment" 301**

- A.1 Objectives and Outcomes, 301
- A.2 Assessment and Evaluation, 307
- References, 308

**B Extracts from the *Syllabus and Notes for the Guidance of Schools for GCE Engineering Science (Advanced) 1972* Joint Matriculation Board, Manchester 311**

- B.1 Extract 1 (pp. 2–6), 311
- B.2 Extract 2 (p. 9), 317
- B.3 Extract 3 (pp. 13–16), 318

Author Index, 325  
Subject Index, 339

---

# Prologue

---

## 1.1 General Introduction: The Functions of Assessment

Recently I had a cause to enquire of a friend how he was recovering from an operation on his heart. He mailed a reply, which said, “They opened my chest, split my sternum, pried my rib cage apart, turned off my heart and lungs and let a machine do the work, replaced my aortic valve with a device fashioned from a cow’s pericardium, cut out a piece of my ascending aorta and replaced it with a Dacron tube, restarted my refurbished heart and lungs, pulled my sternum back in place, and stapled my chest back together. Miracle 1—I’m still alive after all that. Miracle 2—three weeks later, and I’m almost fully functional unaided and what mild aches and pains I have are managed well with gabapentin (a nerve pain pill) and Tylenol.”

“These docs are magicians [...]”

I am sure I would have felt the same. I am not sure that I would have considered it magic but I would certainly have thought it incredible even though hospital “soaps” lead me to believe that such operations are normal every day activity, much more exciting than operations on the brain! Be that as it may, the decision I would have to make, that is, to have or not to have the operation as my friend had to make would have been made on the basis of trust in the surgeons. Such trust is acquired from the understanding that the surgeons have considerable experience at doing such operations and have a not inconsiderable training that enables them to understand that experience as

enabling learning so as to better utilize that experience in the future. That understanding is reinforced by the knowledge that at all the stages in that training the surgeons have been examined or assessed (as some prefer) in formal situations to ensure they can do the job. Moreover, we expect those examinations to be psychometrically reliable and valid so that we can safely assume that the candidate will perform like that in the future. When we go to the surgeon's clinic, we expect to see his credentials, for that is what the accumulated certificates are, hanging on a wall. Should we not expect that from engineering educators?

Fortunately, we do not often have to trust surgeons but there are others in whom we have to place continuing trust, for example, the members of our family. Like them are the teachers to whom we trust our children. In the United Kingdom and the United States, that trust expects the teachers to act *in loco parentis* in activities that go well beyond the classroom although this is not the case in some European countries like France and Germany, where the teaching role is a teaching role without any social attachments. A great deal more is expected of teachers in boarding schools. Just like the surgeons, the trust extended to teachers is helped by the knowledge that they have had a similar training although not as long. They have acquired the knowledge that will enable them to teach a specialism; we expect a person who teaches mathematics to have a qualification in mathematics. But just as we expect surgeons to have gained a high level of craft skill, so many of us expect teachers to have developed the craft of teaching, or as it is more properly called pedagogy. I say many rather than all because there are individuals, politicians among them who think teaching is an intuitive activity that anyone can do. Their expectations do not stretch much beyond the experience of the teaching in their own school which they took to be easy. They find it difficult to believe that there is a serious activity of pedagogical reasoning that requires training on which experience can be built. As Shulman (1987) wrote, any explanation of pedagogical reasoning and action requires a substantial number of categories (i.e., Comprehension; Transformation [preparation, representation, selections, adaptation and tailoring to student characteristics]; Instruction; Evaluation [including testing]; Reflection, and New Comprehensions). Fortunately, the "many" do expect teachers to have credentials that document they have been trained in the theory and practice of teaching, and that to include assessed practice in real classrooms. There is a creeping realization that teachers exert very powerful influences over our children like no other they will experience, and these experiences can be for good or ill.

One of the primary functions of examinations is to aid the credentialing process. Thus, before a person can become a consultant, they have to perform junior roles and be mentored by senior doctors who all the time are monitoring their performance. There may even be performance tests to be taken. All of these tests are to judge their competency both of knowledge and performance. Knowing that they have had years of training is the first step in establishing trust. Much less is required of teachers although some countries require a period of probation and in some countries they are regularly evaluated by government inspectors in their classrooms.

Examinations and tests—assessments—perform many interrelated functions. For example, while an important function of assessment is to ensure that the goals of the

program are being met, the certification of that achievement provides an individual with a credential.

Credentials are also summative: they bring together all that has been learnt in training and they are gained only if a person demonstrates mastery of both skill and knowledge in some way or another. Examinations and tests (assessments) also function as motivational agents: they make some students very competitive, but all students benefit from the role of examinations and tests as formative agents, that is from the feedback they get about their performance the intention of which is to highlight their strengths and weaknesses. Related to the concept of credentials is the idea of a profession and belonging to a profession. In Britain and the United States, not so much in Europe, value is attached to belonging to a profession. Professions give prestige, status, and esteem (Hoyle, 2001) and in these countries, credentials initiate a candidate into the “tribe” and in some circumstances, they enable the “tribe” to regulate entry into itself. In the United Kingdom, groups seek professional status by increasing the level of qualifications required; for example, nurses are now required to possess a university degree in nursing. To be a professional is a valued goal, notwithstanding the sociological view that the term *profession* has lost its meaning (Runté, 1995).

There has been a long-standing debate about whether or not teaching is a profession. Heywood and Cheville and Heywood (2015) have been bold enough to ask if “engineering educators are professional.” One outcome of the debate about the teaching profession has been a distinction originally drawn by Hoyle (1975, Exhibit 1.1) between restricted and extended professionalism that irrespective of whether teaching is profession or not indicates what we might expect from good and poor teachers. Logically, it would extend to teaching in higher and engineering education in particular.

In the United Kingdom, the issues of status, esteem, and power have continued to bother the engineering profession since the end of the Second World War. They were upset by a finding of Hutchings (1963) that entrants to engineering schools had lower A level grades (see Section 3.1) than those in the sciences and they have bothered about such differences ever since. Similarly, they believe and continue to believe that there is a shortage of qualified engineers. Currently, in the United States it is supposed that there is a shortage of candidates for STEM (Science, Technology, Engineering and Maths) courses.

My friend who is very distinguished in his field of activity went on to say, “I’m ashamed to call myself doctor—I can’t do anything that even comes close.” While I do not happen to believe that is the case I was rather facetious in my reply for I said “on this side of the Atlantic you would not have that problem because we call surgeons ‘Mr’ or ‘Miss’ not doctor which is reserved for physicians!” This is said to point out that there are considerable differences between the educational systems of Europe, the United States, and United Kingdom and therefore with many countries of the old British Empire, where Britain established the systems that they developed. This is particularly true of Australia and New Zealand (Yeung, 2014) and countries in Asia. Canada, in contrast, mirror the system in the United States. Because education structures vary from country to country, establishing data that is transferable is exceptionally difficult. Although everyone is concerned with the basic parameters of examining and testing namely, achievement, validity, and reliability, exogenous variables that are unaccountable influences on the



<b>Restricted Professionalism in Engineering Education</b>	<b>Extended Professionalism in Engineering Education</b>
Instructional skills derived from experience	Instructional skills derived from mediation between experience and theory
Perspective limited to immediate time and place	Perspective embracing broader social context of education
Lecture room and laboratory events perceived in isolation	Lecture room and laboratory events perceived in relation to institution policies and goals
Introspective with regard to methods of instruction	Instructional methods compared with those of colleagues and with reports of practice
Value placed on autonomy in research and teaching	Value placed on professional collaboration in research and teaching
Limited involvement in nonteaching professional and collegial activities	High involvement in nonteaching professional and collegial activities
Infrequent reading of professional literature in educational theory and practice	Regular reading of professional literature in educational theory and practice
Involvement in continuing professional development limited and confined to practical courses mainly of a short duration	Involvement in continuing professional development work that includes substantial courses of a theoretical nature
Instruction (teaching) seen as an intuitive activity	Instruction (teaching) seen as a rational activity
Instruction (teaching) considered less important than research	Instruction (teaching) considered as important as research
Assessment is a routine matter. The responsibility for achievement lies with the student	Assessment is designed for learning. Achievement is the coresponsibility of the institution, instructor (teacher), and student

**EXHIBIT 1.1.** Eric Hoyle's characteristics of extended and restricted professionals among schoolteachers adapted for teachers in higher education (Hoyle, E. (1975). Professionalism, professionalism and control in teaching, in V. Houghton et al. (eds.), *Management in Education: The Management of Organizations and Individuals*. London: Ward lock in Association with Open University Press. See also Hoyle, 2001).

data often make it difficult to ascertain what is actually happening within the system, its teachers, and its students (Berliner, 2014).

Apart from the basic functions discussed earlier in this section and the difficulties of making comparisons, there are, I think, two issues that are common to most assessment systems. The first is illustrated by the text in Exhibit 1.2. It is the opening paragraph of a book that I published on *Assessment in Higher Education* in 1977 (Heywood, 1977). I did not put the last sentence in bold as it is here. In spite of changing structures in the United Kingdom and Ireland, I find that colleagues have an affinity with the picture in that Exhibit. I had titled the chapter after a weekly political satire televised by the BBC and hosted by the late David Frost called "Not so Much a Programme, More a Way of