USING CDIO SELF-EVALUATION FOR QUALITY ASSURANCE AND ACCREDITATION

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ABSTRACT

The Diploma in Chemical Engineering course at Singapore Polytechnic has successfully completed its 5-year CDIO implementation that began in Academic Year 2008. The details of our implementation are covered in another paper entitled "*The Diploma in Chemical Engineering CDIO Experience after 5 Years of Implementation*" prepared for this Conference. This present paper shares the approach taken by the DCHE Course Management Team to align its CDIO implementation and self-evaluation process to the institution's quality management systems and holistic education framework, as well as the requirement spelt out by the Institution of Chemical Engineers (IChemE) UK, which recent re-accredits the course for 5 years from 2012 to 2016.

We firstly outline our internal quality assurance system, known as the Academic Quality Management System (AQMS) which is based on the PDCA (Plan, Do, Check, Act) cycle of the ISO9001:2008 system; and the People Developer Standard (PDS) for developing faculty competency. We show that the CDIO Standards can be readily mapped to the key processes and outcomes of AQMS and PDS requirements. Secondly, we evaluate our implementation effort by comparing work done against the CDIO Standards and identify areas for improvement. We also map the skill competency in CDIO Syllabus directly to the graduate attributes of SP Holistic Education, as well as IChemE's outcome-based accreditation criteria which calls for an integrated curriculum embedded with general transferable skills (i.e. CDIO skills), topics on ESH (environmental, safety and health) as well as ethics and sustainable development.

Lastly, we conclude, through our recent re-accreditation, that our success in meeting the IChemE requirements is largely due to our systematic process of curriculum redesign using CDIO, focusing on delivering the best learning experience for students; rather than with any explicit intention of meeting accreditation criteria per se.

KEYWORDS

Self-evaluation, accreditation, quality management and audit, continual improvement, chemical engineering

NOTE: Singapore Polytechnic uses the word "courses" to describe its education "programs". A "course" in the Diploma in Chemical Engineering consists of many subjects that are termed "modules"; which in the universities contexts are often called "courses".

INTRODUCTION

The Diploma in Chemical Engineering (DCHE) of Singapore Polytechnic (SP) embarked on a journey to revise and reorganize – "revamp" - its 3-year curriculum using the CDIO Framework beginning late 2006 post the CDIO Conference in Montreal, Canada. The revised curriculum was rolled out in April 2008, in the beginning of Semester 1 of Academic Year (AY) 2008, for the first cohort of 120 Year 1 students to learn chemical engineering delivered "the CDIO way". The time of this writing (i.e. March 2013, which is the end of AY2012), marked the conclusion of DCHE's 5-year CDIO implementation plan that had started in April 2008. Details of work done are covered in a separate paper by the first author for this Conference [1].

Following our adoption of the CDIO Framework, various educational initiatives had been introduced into the curriculum by the DCHE Course Management Team's (CMT) over the last 5 years. Kontio [2] had reported that educational initiatives, which he explained as "a framework that describes and defines what and how the education should be to develop education for better quality", have a significant role in promoting quality assurance of higher education institutes. Hence, the logical next step for the CMT is to embark on a self-evaluation exercise using the 12 CDIO Standards to review its revamp effort. There are 2 parts to this effort: we first map the self-evaluation process using the CDIO Standards into the institution's internal quality assurance mechanism. Such alignment is essential to manage any perceived workload increase – always a contentious issue – resulting from quality improvement exercises. We then map the SP-CDIO Syllabus, which is customised to include desired graduate attributes of SP's Holistic Education (HE) Framework, to the accreditation criteria from the Institution of Chemical Engineers (IChemE) UK, which accredits our course.

BRIEF INTRODUCITON: QUALITY ASSURANCE IN SINGAPORE POLYTECHNIC

At the national level, all diplomas offered by polytechnics in Singapore must comply with the Polytechnic Quality Assurance Framework (PQAF) outlined by the Ministry of Education (MOE). Within SP, we have the Quality and Environmental Management System (QEMS) to guide us in our operations in delivering quality education to our students. In general, the contents of the QEMS are laid out to address the requirements of ISO 9001:2008 and ISO 14001:2004. For the purpose of this paper, we focus on a "quality" part of the QEMS, which is known as the SP Academic Quality Management Systems (AQMS); which helps to ensure the following:

- consistent quality in the education and training offered by SP
- continuous self-learning and quality enhancement and development within the polytechnics and across the polytechnic sector
- graduates that we produce stay relevant to the needs of industry

Supporting the QEMS is the People Developer Standard (PDS). The PDS is a mark conferred by a government agency in Singapore, which, through a certification process, gives recognition to organizations that invest in their people and have a comprehensive system to manage effective professional development. The certification is carried out by an external assessor and needs to be renewed every 3 years.

The AQMS serves as underpinning foundation for the SP Holistic Education Framework which incorporates CDIO as the curriculum development tool to review and structure our courses and modules, and to shape the SP learning experience in order to achieve our desired 'T-shaped' graduate whose possesses the attributes to be "Life-ready, work-ready and world-ready". The

SP AQMS is shown in Figure 1. Supporting it are 4 key processes: (i) Course identification, design and development; (ii) Course delivery, (iii) Student assessment; and (iv) Course evaluation. Supporting the processes is the Staff Development Plan (SDP) which is an essential component of PDS. The SDP is the mechanism in which a faculty identify his/her training needs and through discussion with the Reporting Officer, jointly formulate the faculty's development program.

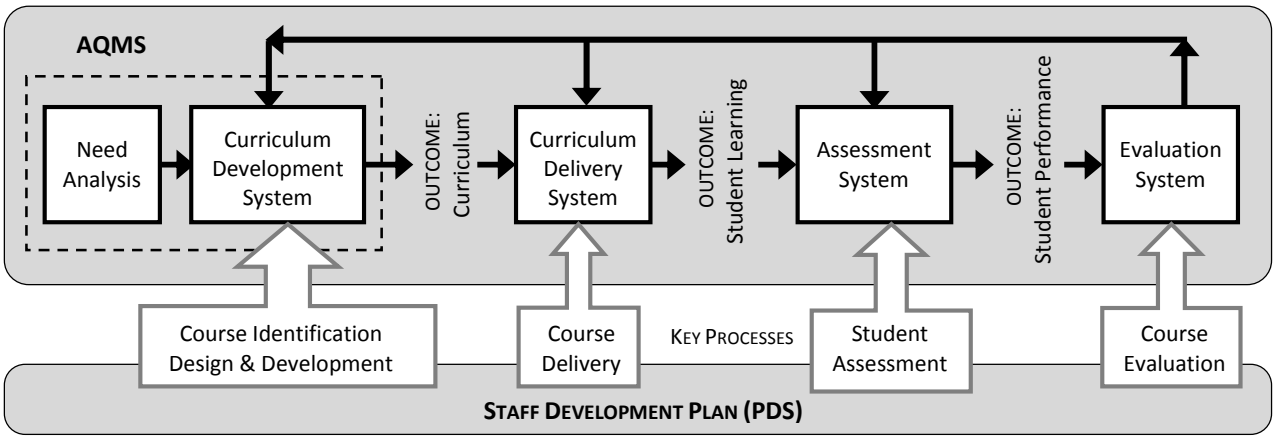

Figure 1. Singapore Polytechnic AQMS Framework supported by PDS

ALIGNMENT AND ACHIEVEMENT OF QUALITY EDUCATION

As one of the courses in SP, DCHE naturally complies with the requirements of AQMS and PDS. With our adoption of CDIO, we strive to deliver quality education to our students, by continually improving our curriculum, via self-evaluation using the CDIO Standards. We also used the CDIO Standards and Syllabus to guide us in our effort to redesign the curriculum, with learning outcomes to produce students with the desired graduate attributes under our Holistic Education Framework.

Hanrahan [3] noted that the provision of quality education is based on the interaction between 3 elements of educational program design, quality assurance and program accreditation. The 3 elements work as follows: First, the standards set by the accrediting body define the required attributes of the graduate as well as knowledge requirements. Second, the engineering programme is designed with educational objectives and assessable outcomes that are evidence that the programme meets its objectives. Third, the educational programme is subject to an external quality assurance process that evaluates the achievement of the programme against the standard and other criteria such as programme structure, the quality of teaching and learning and the resourcing and sustainability of the programme. In our context, the three interacting elements can be represented schematically as shown in Figure 2.

Specifically, we designed our educational program using the CDIO framework; and introduced various initiatives to revamp the curriculum to make it more engaging and interesting to students. In terms of quality assurance, we mapped the CDIO Standards into existing SP AQMS and PDS; which we use to continually improve our curriculum and build faculty competency. Lastly, we also mapped the CDIO syllabus to graduate attributes of SP Holistic Education Framework, and used that as the basis for program accreditation from an external professional body, in this case, the IChemE.

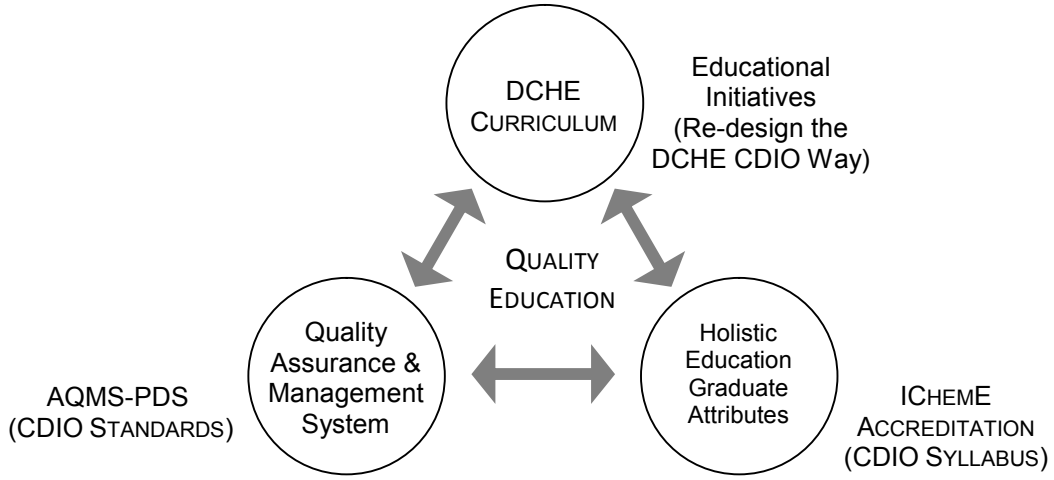

Figure 2. Achievement of Quality Education

DCHE is one of the few courses in SP that is accredited internationally. We feel that the IChemE accreditation provides the independent recognition of the quality of our chemical engineering education; demonstrating that our course provided our graduates with the desired learning outcomes that meet industry requirements. Gray [4] aptly noted this in the book *Engineering Education Quality Assurance: A Global Perspective*:

> "With the rapid globalization of higher education as well as related changes in social, political, economic, and other conditions over the last 25 years there have been ever increasing expectations for higher education, in general, and Engineering Education, in particular. These expectations are often expressed in terms of the need for Quality Assurance locally, regionally, and globally (p.v)"

In short, we have put in place a system that ensures continual improvement of our curriculum to deliver quality education to our students; and the integrity of the system is maintained and improved upon by subjecting it to assessment by independent, third-party assessors.

INTEGRATING CDIO SELF-EVALUATION INTO AQMS-PDS

Brodeur and Crawley [5] noted that the CDIO Standards serve as a useful framework for internal program self-evaluation and external Quality Assurance; and that the founding members of CDIO had been using this model of self-evaluation since October 2000. The authors also noted that the key Quality Assurance questions, which are aligned with the CDIO Standards [6], can be applied to any program in any discipline.

The CDIO standards-based program evaluation focuses on outcomes, particularly student learning outcomes and student satisfaction, and process, particularly teaching, learning, and assessment in a design-build environment; compared to an explicit set of expectations [5]. The standards and self-evaluation therefore provides opportunities to not only rate current status, but also plan specific actions for continuous program improvement [4]. In our case, we likewise argued that there is strong alignment in the goals of CDIO self-evaluation and our AQMS-PDS, and by extension, to parts of the PQAF, the national requirements.

Figure 3 shows the program evaluation framework aligned with the 12 CDIO Standards [5]. Note that program evaluation is itself one of the standards. Self-evaluation using the CDIO Standards provided us with the systematic methodology of PDCA (Plan Do Check Act) cycle to drive the continual improvement effort. In comparing Figure 1 and Figure 3 it is apparent that there is clear alignment between our AQMS-PDS and CDIO Standards, as shown in Table 1.

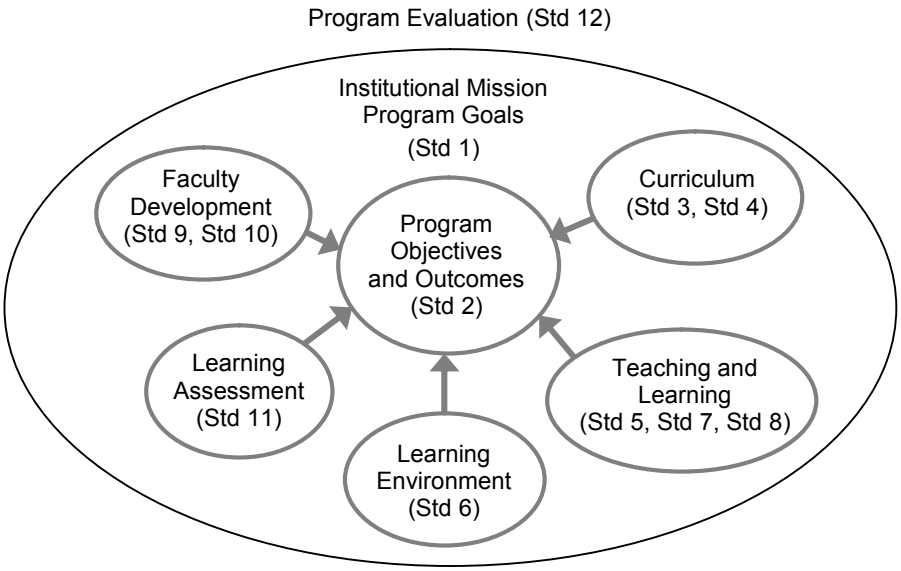

Figure 3. Program evaluation aligned with CDIO Standards

Table 1. Mapping between CDIO Standards and SP AQMS-PDS

Item	Description	CDIO Standard(s) Mapped
AQMS	Need Analysis	1 CDIO as Context
	Curriculum Development System	2 CDIO Syllabus Outcomes
	Outcome: Curriculum	3 Integrated Curriculum 4 Introduction to Engineering 5 Design-Implement Experiences
	Curriculum Delivery System	6 CDIO Workspaces 8 Active Learning
	Outcome: Student Learning	7 Integrated Learning Experiences
	Assessment System	11 CDIO Skills Assessment
	Outcome: Student Performance	
	Evaluation System	12 CDIO Program Evaluation
PDS	Capability Building	9 Enhancement of Faculty CDIO Skills
		10 Enhancement of Faculty Teaching Competence

The DCHE Self-Evaluation: Findings and Discussions

As part of our continual improvement in CDIO implementation, we carried out a self-evaluation exercise, and compared the results against an earlier evaluation conducted in 2008, shortly after we introduced our CDIO-enabled curriculum for the first time.

It is important to note that for the 2012 self-evaluation we used the newly-refined generic rubric featuring a six-point rating scale (0-5). The rubric has been designed deliberately to encourage planning and allow various styles of implementation and adoption [5]. Criteria for each level are based on the description and rationale of the Standards and highlight the nature of the evidence that indicates compliance at each level [4]. Also, the rubrics are cumulative, that is, each successive level includes those at lower levels. For our self-evaluation, we noted that there exist subtle differences between this rubric and the earlier one with five-point rating scale (0-4) used in 2008. For comparison purposes, we re-rate our 2008 self-evaluation submission using the six-point rating scale. The comparison between these self-evaluations is shown in Table 2.

Table 2. Comparison of CDIO Self-Evaluation

CDIO Standard	Rating from Self-Evaluation		Proposed Action Plan
	2008	2012	
1	3	5	Regularly communicate the "CDIO-way" of teaching and learning to all stakeholders, especially students
2	3	4	Continue with "cluster review" of related modules, continue to refine all written syllabi to ensure clarity of learning outcome
3	3	4	Review Course Structure vis-a-vis sequential model for more effective integration, as well as knowledge and skill transfer To introduce more problem-based learning (PBL) into selected core module(s), and introduce assignments that are multi-disciplinary in nature; and review activities to promote transfer of skills across modules and year of study
4	3	4	Continue to monitor understanding of chemical engineering and interest in the field among new cohort of Year 1 students
5	3	4	Tweak existing activities, especially at basic-level to continue to pique student interests in the field; review advanced-level assessment scheme to integrate design thinking, ethics, SD, etc
6	3	3	Continue to seek management support for new workspace – this is perhaps the most challenging part of the continuous improvement process yet; and to rationalize existing space
7	3	4	Review if possible to use same case study/scenario for different modules, and built on prior learning in earlier modules Enhance learning experience via out-of-classroom activities during education of sustainable development using "appropriate technology"
8	3	4	To expand into tutorials with more discussion, role play or presentation; and lectures for example by using Concept Questions, or Think-Pair-Share, etc
9	3	4	Conduct training needs analysis; identify training opportunities for lecturers to undergo training related to teaching and assessing new skills, e.g. reflective practice, lifelong learning, ethics, etc
10	3	4	
11	2	3	Explore use of suitable survey instruments to assess some of the identified new skills, e.g. how to handle ambiguity Explore how to assess transferability of knowledge and skills across modules and year of study
12	2	3	Fine-tune the integration of CDIO Self-evaluation process into the AQMS-PDS Framework

As can be seen from the table, while we made significant improvements in most areas, there had been no progress on Standard 6. This is due to the limited real estate in Singapore in general; and SP in particular. As such, we continued to make do with existing laboratory facilities, and we believe that despite this limitation, we are able to achieve remarkable results during the 5 years of our CDIO adoption process. The 2 other areas where progress is slower is in Standards 11 and 12. Especially for the latter, we rate ourselves low in 2012 despite making significant inroads trying to map the CDIO Syllabus and Standards to our existing quality assurance and accreditation mechanisms.

CDIO AND PROGRAM ACCREDITATION

The CDIO Standards and self-evaluation process have been used to provide the foundation for meeting accreditation expectations. Armstrong et al [6] explained the fundamental difference in intent between accreditation criteria and CDIO requirements, noting that the purpose of accreditation is to ensure that engineering programs meet a minimum standard and hence accreditation criteria are threshold criteria. In contrast, CDIO requirements represent a higher standard or benchmark that CDIO collaborators believe is possible in engineering education. The full coverage of the CDIO Syllabus should be a goal that programs strive for through continuous improvement. He suggested that since the CDIO Syllabus is applicable internationally, it is likely to be much more comprehensive than any future international accreditation criteria. The CDIO Self-evaluation, which is based on a rating scale, is used for continuous improvement compared to a threshold value scale that is used in accreditation. In this sense, CDIO requirements are aspirational, and accreditation criteria and CDIO requirements are complementary, since there is no incompatibility between meeting minimum requirements and aspiring to a higher standard.

IChemE UK Accreditation for DCHE

As mentioned previously, the DCHE course is unique in the sense that it is among the few SP diplomas that had sought and obtained external professional accreditation; in this case by the IChemE. The IChemE recognized the importance of accreditation in the context of chemical engineering, noting that “the learning outcomes specified in this guidance comprise a package which is distinctive to chemical engineering, and which can be regarded as a minimum necessary requirement for IChemE accreditation” [7]; where the last point clearly illustrate the threshold nature of its accreditation criteria.

The IChemE accreditation guidance has the following high-level general learning outcomes: *Knowledge and understanding*, *Intellectual abilities, Practical skills* and *General transferable skills*. These outcomes are to be covered under six categories: underpinning mathematics and science, core chemical engineering, engineering practice, design and design engineering, essential embedded learning (sustainability, ethics, SHE) and essential embedded learning (transferable skills).

In this case we mapped the CDIO Syllabus to IChemE’s learning outcomes, similar to the one reported by Karpe et al [8]. The results clearly show that by redesigning our curriculum using the CDIO Framework, our course is able to meet all the IChemE requirements, most significant of which the form of embedded learning of general transferable (i.e. CDIO) skills, SHE, ethics and sustainability.

KEY LEARNING POINTS

We have aligned our curriculum revamp effort using the CDIO framework by systematically mapping key competency areas and skills from the CDIO Syllabus to our own institutionally derived graduate attributes and IChemE's learning outcomes. This resulted in an integrated curriculum in which the coverage of technical subject content and selected generic transferable CDIO skills (e.g. ethics, sustainable development, etc) were consistent with accreditation requirements.

A number of important lessons stand out. In the recent IChemE reaccreditation in May 2012, DCHE found itself in a unique situation to be able to compare its experience against the earlier accreditation in 2007, just before we embarked on our CDIO journey. It is worth noting that the 2012 re-accreditation was based on new IChemE criteria which, in turn, are based on the course achieving its intended learning outcomes and integration of generic skills (i.e. CDIO skills, which IChemE termed "general transferable skills"), which is substantially different from the criteria used in the 2007 exercise. It is therefore of interest to us to compare our experience in IChemE accreditation before and after adoption of CDIO.

Upon closer reflection, we can say that our success in meeting the IChemE requirements in the 2012 re-accreditation is largely due to our systematic process of curriculum redesign using CDIO, focusing on delivering the best learning experience for students; rather than with any explicit intention of meeting accreditation criteria per se. During our curriculum redesign effort, we remained focused on the task at hand, immersing ourselves in the "CDIO-way of doing things". We were able to quickly prepare the documentary evidence needed for the panel's review both before arrival and during the site visit. Through CDIO, we are able to convincingly demonstrate to the assessors, during their site visit, that the diploma had, in fact, exceeded IChemE's requirements in this area.

While having achieved reaccreditation served as a "mark of approval" with regards to the quality of our chemical engineering education, we are also mindful of the need to continually improve our diploma if we want to ensure that our graduates had indeed been imbued with the desired attributes after having spent 3 years with us. We find the CDIO self-evaluation process useful in helping to pinpoint specific areas for review as opposed to the more generic requirements for continual improvement typically covered in quality assurance models.

Between continual improvement and quality audit (accreditation), it is clear to us that emphasis should be placed on the former. In this regards, we were reminded by Adamson et al [11] that the difficulties in drawing conclusions about educational quality from a learning outcome perspective will increase the further away from the teaching and learning situation the evaluation is carried out. Between the choice of (quality) audits and evaluations of study programmes/subjects there is a need to choose the latter in order to tackle the issue at its source". We will use the "CDIO-enhanced" AQMS to continue with curriculum review every academic year to drive the continual improvement effort; and believe that this will in turn provide the support base needed to meet any accreditation requirements.

Lastly, we noted that our experience with CDIO had instilled in us the confidence of accommodating new developments without incurring additional curriculum hours, achieving what Crawley et al terms "dual-impact learning" that promote deep learning of fundamentals and of practical skill sets [9].

MOVING AHEAD AND CONCLUSION

The DCHE CMT will formulate its next 5-year plan to follow-up on the consolidation phase of its current effort after the latest round of self-evaluation exercises [1]. From Table 2 we had identified a number of action items to move forward. We will need to review these items to prioritize the work ahead in terms of faculty capability and available resources; as well as new initiatives within SP, MOE, IChemE or other stakeholders; as briefly explained below.

Within SP, there is a new initiative under the banner of "SP Beyond 2014" to propel the institution forward in its quest to deliver quality education. Part of the requirements of this new initiative is to introduce skills deemed crucial for the 21st century including media literacy, sense-making and information processing. Also, at the time of this writing, IChemE had released an update to its 5-year roadmap first published in 2007 [10]. We will study the document to ensure that our curriculum can appropriately incorporate any new requirements. Most significantly, we are now preparing ourselves for the upcoming teaching and learning review by the MOE next year under the PQAF, especially in the area of teaching and learning.

We believe that by aligning the CDIO self-evaluation process into our quality management system, we now provide greater clarity on the "what" and "how" to continually strive for improvement in the way we deliver our chemical engineering education.

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ACKNOWLEDGEMENTS

The authors would like to thank Mr. Dennis Sale, senior education advisor from the Department of Educational Development (EDU), for his enthusiasm and valuable advice on the paper.

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Quality assurance therefore incorporates several factors and it is an integral part of all key activities in procurement. The implementation of a quality assurance system in procurement, including systems for prequalification, storage and distribution, may affect costs. However, the benefits of ensuring quality outweigh the cost investment because they reduce the possible losses caused by the purchase and supply of substandard products.