A Design Software to Facilitate Learning of Quantitative Critical Thinking by Chemical Engineering Students

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Introduction

- **A covert experiment…**
- **AY2015/2016 Semester 2**
- **Core module CN3124 Fluid-Solid Systems**
- **269 students**

Introduction

QUESTION 4 Answer ALL parts (a), (b) and (c) **(40 marks)**

An existing pneumatic transport system in a chemical plant consists of a vertical smooth pipe with inner diameter 50 mm and length 50 m. Particles with a mean size of 500 μm and density 3000 kg m^{-3} are transported at a solids mass flow rate of 2500 kg h^{-1}. The blower that is used to deliver air has been in use for many years and its specifications are unavailable. Based on this design of the pneumatic transport system, the total pressure drop across the vertical pipe was measured to be about 0.4 bar. Due to a new requirement of the chemical plant, an additional horizontal pipe with the same inner diameter and length 100 m needs to be added to the existing vertical pipe via a 90° bend on the downstream side of the vertical pipe section. The management of the chemical plant wishes to determine whether the new system can operate at the same solids mass flow rate with the existing blower. The density and viscosity of air are 1.2 kg m^{-3} and 1.85×10^{-5} Pa·s respectively and the terminal velocity of the particles may be taken to be 4.5 m s^{-1}.

(a) Your supervisor in the above chemical company has requested a colleague to perform design calculations for the above problem and she wishes you to evaluate the new design. These design calculations are as follows:

$$\Delta P_v = \frac{\rho_f \varepsilon_v U_{fv}^2}{2} + \frac{\rho_p (1-\varepsilon_v) U_{pv}^2}{2} + \frac{2 f_g \rho_f U^2 L_v}{D} + 0.057 G L_v \sqrt{\frac{g}{D}} + \rho_p (1-\varepsilon_v) g L_v + \rho_f \varepsilon_v g L_v$$

Assume $\varepsilon_v \approx 1$, $U_{fv} \approx U$,

$$\Delta P_v \approx \frac{\rho_f U^2}{2} + \frac{2 f_g \rho_f U^2 L_v}{D} + 0.057 G L_v \sqrt{\frac{g}{D}} + \rho_f g L_v = 0.4 \times 10^5$$

$$G = \frac{2500}{3600} \frac{1}{\frac{\pi (0.05)^2}{4}} = 353.7 \text{ kg m}^{-2}\text{s}^{-1}$$

$$Re = \frac{\rho_f U D}{\mu} = 3243U \Rightarrow f_g = 0.01U^{-0.25}$$

$$\frac{1.2U^2}{2} + \frac{2(0.01U^{-0.25})(1.2)U^2(50)}{0.05} + 0.057(353.7)(50)\sqrt{\frac{9.81}{0.05}} + (1.2)(9.81)(50) = 0.4 \times 10^5$$

$$0.6U^2 + 24U^{1.75} = 25292$$

By trial-and-error, U = 51.4 m s^{-1}

∴ Air flow rate = 0.10 m^3 s^{-1}

$$\Delta P_H = \frac{\rho_f \varepsilon_H U_{fH}^2}{2} + \frac{\rho_p (1-\varepsilon_H) U_{pH}^2}{2} + \frac{2 f_g \rho_f U^2 L_H}{D} + \frac{2 f_p \rho_p (1-\varepsilon_H) U_{pH}^2 L_H}{D}$$

Assume $\varepsilon_H \approx 1$, $U_{fH} \approx U$,

$$\Delta P_H \approx \frac{\rho_f U^2}{2} + \frac{2 f_g \rho_f U^2 L_H}{D} = \frac{1.2(51.4)^2}{2} + \frac{2(0.01)(51.4)^{-0.25}(1.2)(51.4)^2(100)}{0.05} = 48947$$

∴ $\Delta P = 0.4 \times 10^5 + 48947 = 0.89$ bar

Evaluate the above design of the new pneumatic transport system proposed by the colleague critically, identifying and explaining all errors and/or weaknesses present in the design. (15 marks)

(b) Design a set of operating parameters for the new pneumatic transport system based on the new requirements set by the management. Hence, or otherwise, formulate a set of specification criteria which can be applied to evaluate whether the existing blower can be used in the new system. (20 marks)

(c) The management decides to acquire and install a new blower for the new pneumatic transport system. In anticipation of future expansion plans, a blower that is able to deliver air over a range of volumetric flow rates and a range of operating pressures is being considered. Determine the volumetric flow rate of air that the blower should be able to deliver if the solids mass flow rate needs to be increased to twice its current value. (5 marks)

END OF PAPER

Literature Review

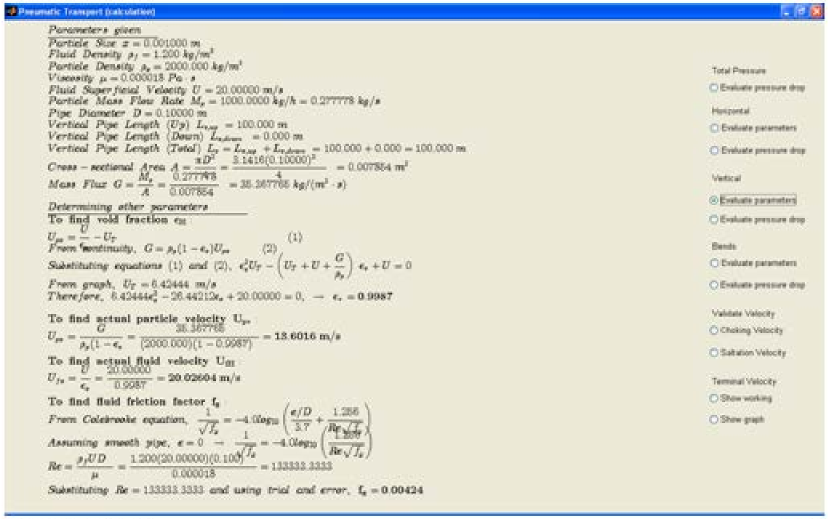
- **Critical thinking skills cannot be acquired implicitly as a natural outcome of college education (Abrami et al., 2008)**
- **Teaching critical thinking in major-related domains is more practical than in general domains (Huber and Kuncel, 2016)**
- **Critical thinking is seldom emphasized through deliberate interventions**
- **Critical thinking can be taught and the key element is repeated practice (Holmes et al., 2015)**

Abrami, P. C., R. M. Bernard, E. Borokhovski, A. Wade, M. A. Surkes, R. Tamin, D. Zhang. Review of Educational Research, 78(4), 1102-1134. 2008.

Huber, C. R., N. R. Kuncel. Does college teach critical thinking? A meta-analysis. Review of Educational Research, 86(2), 431-468. 2016.

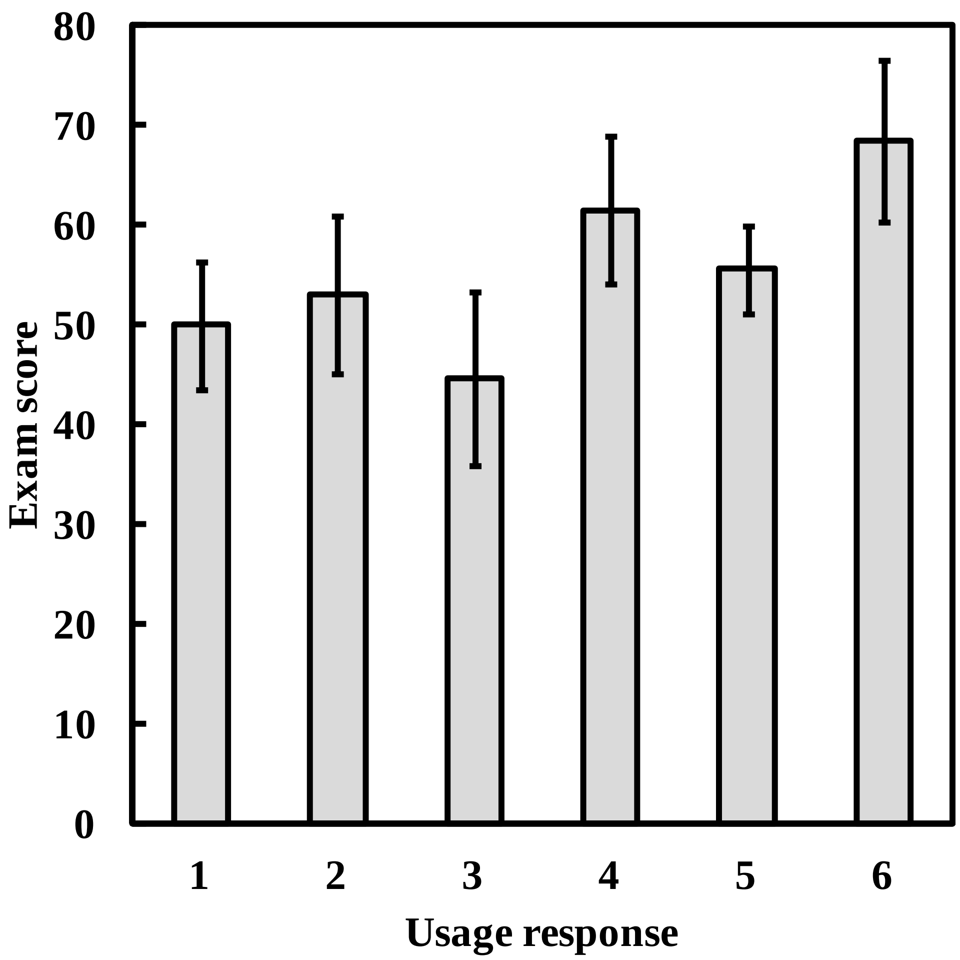
Holmes, N. G., C. E. Wieman, D. A. Bonn. Teaching critical thinking. Proceedings of the National Academy of Sciences of USA, 112(36), 11199-11204. 2015.

Method



- Existing design software developed in a previous TEG project
- Enhanced students’ learning via repeated practice approach
- Scalable to large class sizes
- Effective in overcoming constraints of limited classroom hours

Results and Discussion



Lim, E. W. C. A Design Software to Facilitate Learning via Repeated Practice by Chemical Engineering Students. Education for Chemical Engineers, 21, 72–79. 2017.

Method

Fluidization (Critical Thinking)

Evaluate the following solution critically, identifying and explaining all errors and/or weaknesses present.

○ Minimum Fluidization Condition
◉ Bed Condition
○ Find n and Ut

Parameters given

Particle Size $x = 0.001000\ m$

Fluid Density $\rho_f = 1000.000\ kg/m^3$

Particle Density $\rho_p = 2000.000\ kg/m^3$

Viscosity $\mu = 0.001000\ Pa \cdot s$

Mass of Particles $M_p = 500.0000\ kg$

Bed Diameter $D = 0.50000\ m$

Bed Height $H = 2.000\ m$

Cross − sectional Area $A = \frac{\pi D^2}{4} = \frac{3.1416(0.50000)^2}{4} = 0.196350\ m^2$

Fluid Superficial Velocity $U_{fs} = 0.05000\ m/s$

Minimum Fluidization Velocity $U_{mf} = 0.00455\ m/s$

Determining frictional pressure drop across the bed when $U_{fs} = 0.05000$

From Ergun equation : $\frac{(-\Delta p)_{fric}}{H} = 150\frac{(1-\epsilon)^2\mu U_{fs}}{\epsilon^3 x^2} + 1.75\frac{(1-\epsilon)\rho_f U_{fs}^2}{\epsilon^3 x}$

Substituting the corresponding values :

$$\frac{(-\Delta p)}{4.769} = \frac{150(1-0.73299)^2(0.001000)(0.05000)}{(0.73299)^3(0.001000)^2} + \frac{1.75(1-0.73299)(1000.000)(0.05000)^2}{(0.73299)^3(0.001000)}$$

→ Frictional pressure drop $(-\boldsymbol{\Delta}\mathbf{p})_{\mathbf{fric}} = \mathbf{20618.8508\ Pa}$

From Bernoulli equation : $\frac{p_1 - p_2}{\rho_f g} + \frac{U_1^2 - U_2^2}{2g} + (z_1 - z_2) = friction\ head\ loss = \frac{(-\Delta p)_{fric}}{\rho_f g}$

For constant bed diameter $U_1 = U_2$

$z_1 - z_2 = -H = -4.769\ m$

Therefore, $(-\Delta p)_{total} = \rho_f g H + (-\Delta p)_{fric} = (1000.000)(9.81)(4.769) + (20618.8508) = \mathbf{67398.4652\ Pa}$

Determining final porosity and bed height

From Khan and Richardson correlation, $n = 2.8386$

From graphical method, single particle terminal velocity, $U_T = 0.12075\ m/s$

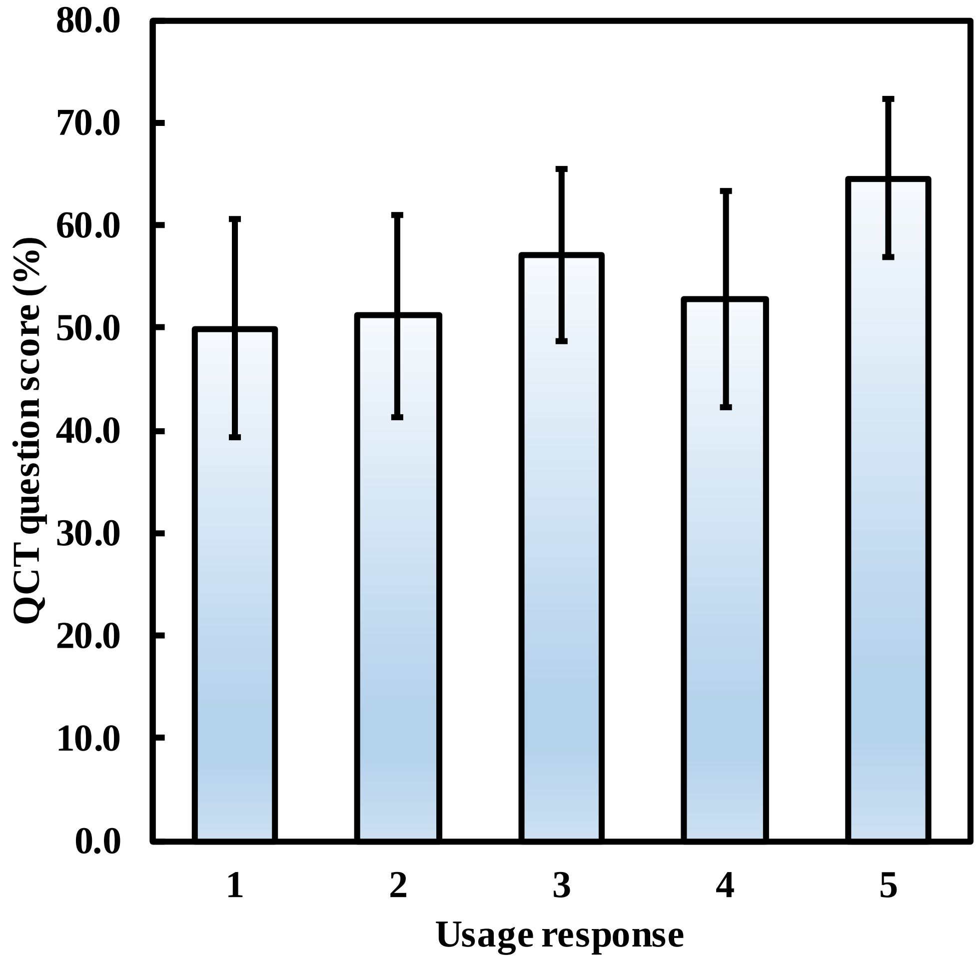
Use Richardson − Zaki equation $U = U_T\epsilon^n$ to estimate final porosity :

$0.05000 = 0.12075\epsilon^{2.8386} \rightarrow \epsilon = \mathbf{0.732993}$

Since total mass of particles remain unchanged, $M_p = (1-\epsilon_2)\rho_p A H_2 = (1-\epsilon_1)\rho_p A H_1$

Hence, $H_2 = \frac{1-\epsilon_1}{1-\epsilon_2}H_1 = \frac{1-0.363380}{1-0.732993}(2.0000) = \mathbf{4.7686\ m}$

Results and Discussion



Conclusions

- QCT software has been successful in enhancing performance of students in solving final examination question requiring critical thinking
- Average marks achieved by students who reported higher frequencies of usage were higher
- Intervention was scalable to large classes, able to overcome constraints of limited classroom hours
- Allowed repeated practice to be applied outside classroom hours and encouraged independent learning

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