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Research Article

AN INSPIRATION FOR ALL TIME: PIONEER VERENA HOLMES' IMPACT ON FUTURE ENGINEERING PRACTICE

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ABSTRACT

Verena Holmes is a pioneer for women in the industry as arguably the first female in the UK to have a full-time career as a professional mechanical, design and biomedical engineer. She was an advocate for widening participation in engineering and dedicated to the development of female engineers. In 1932, Verena Holmes filed a patent for a poppet valve for fluid pressured systems, which in 2022 has provided inspiration for students to conceive, design, implement and operate their own design. The poppet valve project challenges first-year biomedical, mechanical and product design engineering students to consider engineering materials, manufacturing, fixes and fittings, and tolerance considerations. This paper will provide qualitative analysis of the level of practical engineering learning, and the depth of student learning. There is also a quantitative analysis of the students' evaluation of the learning opportunity, to inspire, develop and stimulate them to be the next generation of engineers.

1. Introduction

In higher education in the UK in 2020, 19.7% of engineering students were female (Harrison, 2021); in comparison to the workforce in 2021 which consisted of 14.5% of females (Wilson, 2021). More women leave science, technology, engineering and mathematical subjects upon graduation than men, due to a lack of role models to support their sense of belonging (Meiksins et al., 2019). Herrman et al.'s (2016) story of intervention for targeted provision for female STEM students describes their increased sense of belonging and increased retention. It is important to note that any intervention to support females in engineering should not be to the detriment of male students and others with protected characteristics of disability, ethnicity, colour, sexual orientation, faith, or socio- economics. The perfect intervention should enhance all students' learning, experience and retention in science and engineering.

Scientists' and engineers' roles in society are in their contributions to engineering solutions to problems. Many over the years have worked to produce innovative products to support daily life (Sinclair, 2019). Verena Holmes, in the twentieth century, was one such engineer; an inventor and entrepreneur, with her own engineering business in Gillingham, Kent. In the 1930s, Verena Holmes filed a number of patents to improve engineering solutions or increase the efficiency of a process, from guillotining paper, biomedical engineering respiratory devices to a poppet valve for automated fluid pressured systems (Holmes, 1931).

The role of academics is to educate and facilitate student learning (Biggs, 1989; Murray and Macdonald, 1997; McCabe and O'Connor, 2014); while the role of the engineering academic is also to mentor, influence and inspire the next generation of diverse and inclusive engineers for industry and society (Davies et al., 2006). Embedding engineering pioneers such as Verena Holmes provides an opportunity to inspire the next generation of engineers:

- to make a similar or greater impact through inclusive engineering design (Waller et al., 2015)
- to contribute to society, industry and the regional, national and global economy through innovation and entrepreneurship (Refaat, 2009) and the development of student self-efficacy (Duval-Couetil, Reed-Rhoads and Haghighi, 2012)
- to apply their engineering learning to solve problems and improve their long-term employability (Strobel and Pan, 2011)
- to have a sense of belonging, in particular for female engineers in education and industry (Black, Mendick and Solomon, 2011)

The main aims of this paper are to provide a qualitative analysis of the level of practical engineering learning and the depth of student learning; as well as a quantitative analysis of the students' evaluation of the learning opportunity, in order to develop their engineering technical skills, and inspire, develop and stimulate them to be the next generation of engineers.

In terms of practical engineering learning, the paper seeks to address the impact of Verena Holmes' engineering solution on inspiring students to innovate and improve on her 1932 patent (Holmes, 1932) of an invention to improve a valve design for a fluid pressured system, i.e. her invention of the poppet valve (Holmes, 1931). The pedagogy approach adopted and implemented was a time-constrained practice-based learning exercise, whereby the students were presented with the opportunity to conceive, design, implement and operate (CDIO) their own poppet valve over two days. This approach is aligned and supports Canterbury Christ Church University's, School of Engineering, Design and Technology commitment to adopt, embed and implement Crawley et al.'s CDIO pedagogy (2011) in the delivery of the engineering curriculum. The student pedagogy method of evaluating the students' solutions (formative submissions) that has been adopted is James and Pollard's (2015), and DET (2000). This paper presents the analysis of six case studies (six different groups of students' solutions to the problem), to determine if the students' perception of their engineering learning matches their actual in-depth learning demonstrated through their application and experimentation to innovate a poppet valve.

The paper also seeks to evaluate through a quantitative method the impact of the project on the students' perception of their learning about engineering technical skills. The paper presents a quantitative analysis of the students' evaluation of the learning opportunity to inspire, develop and stimulate them to be the next generation of engineers, learning both in terms of:

- Their learning, development, and application of first-year engineering technical skills as defined by the UK Engineering Council fourth edition accredited higher education programme of learning for the first year of an engineering degree.
- The impact which Verena Holmes' patent for the poppet valve had on inspiring them to learn per se, innovate, and learn about Verena Holmes, along with equality and diversity of engineering and inclusive engineering.

2. Methodology

Pedagogy Learning Delivery Model

Canterbury Christ Church University is committed to providing engineering students with a higher education experience that equips them for success with their personal aspirations and in making a wider contribution to society, beyond graduation. To achieve this, the engineering curriculum has adopted CDIO pedagogic philosophy.

The rationale for adopting the CDIO approach is that it was developed specifically to meet the needs of employers. The CDIO (conceive, design, implement and operate/observe) (www.cdio.org) is a four-stage engineering project framework:

- The conceive stage develops the student's ability to research, identify and define a problem and generate ideas that are possible solutions to the problem.
- The design stage focuses upon developing the project plans and designs of their chosen solution to the problem.
- The implement stage covers the implementation of their design to produce a prototype solution, an alpha release.
- Then the operate/observe stage gives students verification and validation through a critical evaluation of their prototype solution, identifying improvements.

Qualitative Evaluation

Pedagogy Evaluation Method

The pedagogy evaluation method used to evaluate the student learning from their formative assessment submissions was from James and Pollard (2015) and DET (2000). This approach was used as it provides an appropriate framework to enable a lecturer to evaluate the effectiveness of the academic team in imparting useful knowledge to their students, and how effective the learning opportunities had been to enable students to research, think and learn for themselves. Also, it meets the long-term learning aspirations from government for higher education where the students' learning is in-line with the goals of the society it is meant to serve (James and Pollard, 2015).

Working by James and Pollard's (2015) principles effectively empowers learners throughout their learning curves up to the point that they can learn for themselves without any supporting frameworks. The image below is a summary of a pedagogical model which addresses student achievement, engagement, and wellbeing.

Figure 1: The pedagogical model (DET, 2000)

Student Learning Activity Background

The background to this student learning activity (the CDIO project activity) is based on the legacy of Verena Holmes who was responsible for the design of one of the most useful devices in the field of engineering today: the poppet valve (Holmes, 1931). The image below summarises each part and their key functions. When the actuator is pushed down, fluid is allowed to flow from port P to port A. This happens when the valve disc is pushed down, and the return spring underneath the ball is compressed. Fluid flows from point P to A as long as the actuator stays compressed. Once it is released, the ball closes the exit point through which the fluid flows (Parr, 2011). This is an example of a simple poppet valve. Other variations of the same product have been made.

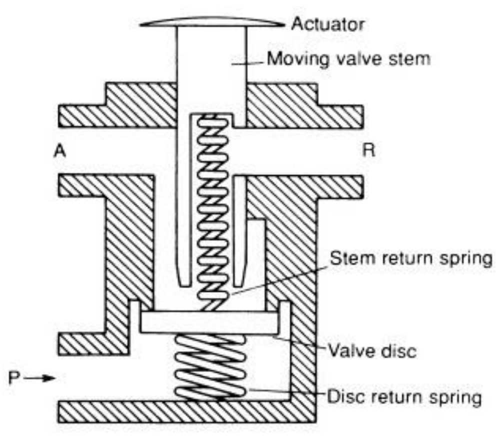

Figure 2: An example of a 3/2 normally closed poppet valve (Parr, 2011)

With this basic knowledge of the operation, history and importance of the poppet valve, students were challenged to design their own poppet valve. They were provided with:

- The Design and Manufacturing Laboratory Brief that provided the background to the time-based learning project activity.
- Verena Holmes' *Patent for Improvements in valve gear for fluid pressure units, 1932,* (Holmes, 1932)
- Verena Holmes' paper on her new infinitely variable poppet valve, 1931, (Holmes, 1931)

The academics facilitated the student learning, promoted the students to apply the materials and manufacture module learning to the project activity. This entailed challenging the students to consider various materials, manufacturing processes, material selection methods, design for manufacture, life cycle analyses among other industrial practices that engineers apply when designing and manufacturing products.

From a literature review on research methods, it can be determined that there is no consensus in the research community on the sample size of a qualitative research study; whereas the broadly accepted thresholds are suggested as 3 to 20 samples depending on availability and data size (Fernández-Gómez et al., 2020). Accordingly, six formative case study reports were analysed in-line with these desired research points, as well as the ten pedagogy principles, so that qualitative and quantitative analyses on personal development and inspiration as well as practical learning could be evaluated. The case studies are discussed in the following sub-sections.

Case Studies

In these case studies, students explored the design and manufacturing of poppet valves, acknowledging the work of Verena Holmes and focusing on various approaches from historical research to practical application. They faced challenges such as measuring dimensions accurately and adapting to manufacturing limitations, particularly in 3D printing and CAD modelling. Each group employed different methods: some prioritized technical aspects like the operation of the valve and component repurposing, while others emphasized the design process, including initial sketches, CAD modelling, and rapid prototyping.

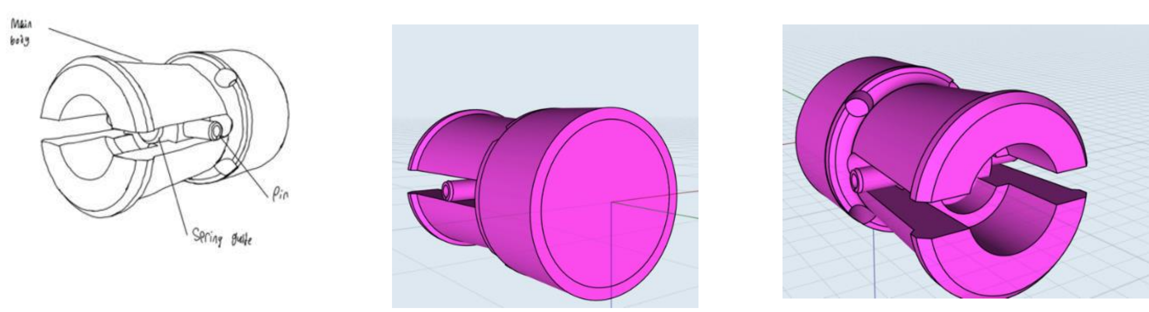

Figure 3: The final CAD model from group two for the designed poppet valve

Despite encountering issues like tolerance errors and size discrepancies during prototyping, the students learned valuable lessons in design and manufacturing. They demonstrated an understanding of the technicalities involved in valve operation and manufacturing, incorporating contemporary methods and acknowledging historical developments. These experiences, ranging from addressing specific design challenges to acknowledging historical influences, culminated in a diverse yet cohesive learning journey, showcasing the students' ability to adapt and innovate in the field of mechanical design.

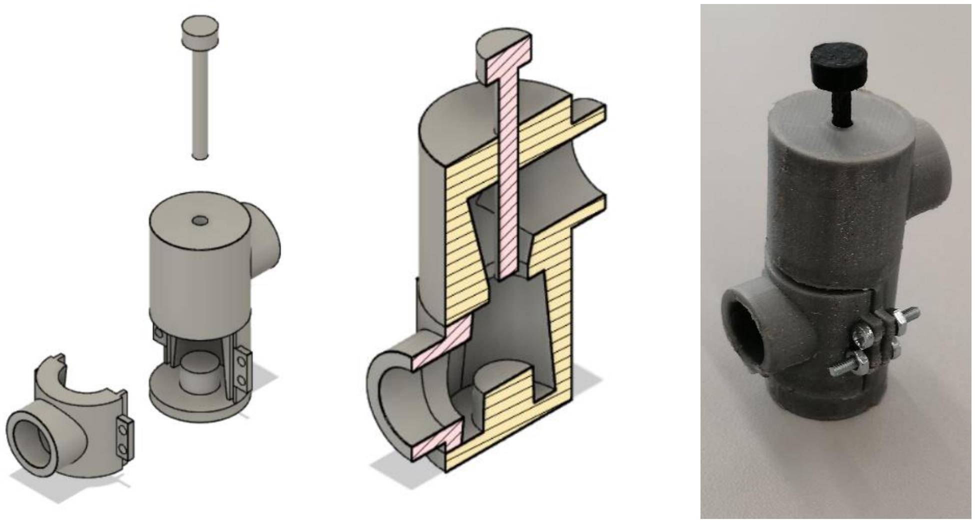

Figure 4: The poppet valve designed on CAD (left), its cross-section (middle) and the final product made using rapid prototyping (right) from group five

Qualitative Results' Discussion

The case studies show that all of the reports contained mainly practical and pragmatic approaches to solving the design and manufacture problems highlighted in the project brief. In terms of practical engineering learning, some of the students not only demonstrated a good understanding of the operation of poppet valves, but they also showed good research skills in finding credible sources to substantiate their findings and explain the working of said valve. The students in this case managed to do that as they all produced a finished component.

Overall, the level of practical engineering learning is high, and given that this work is done by first-year students in one day, it comes to show how much potential they have. The depth of their learning is also commendable going by the quality of technical work demonstrated in the reports, but they could use more detail. This will be addressed as the students progress in their education, as it is one of the main learning points in engineering disciplines across universities. However, the lack of feedback on inspiration for being engineers of the future is an area that will need to be addressed. Whether it is a mistaken or deliberate oversight by the students is something that needs to be determined, especially because it is a key part of this assignment. Finally, in relation to the ten principles of pedagogy, the support staff can use the findings in this report to create conducive learning environments for the students to further develop their technical skills while working to improve their interpersonal skills.

Quantitative Evaluation Method

A quantitative evaluation method was also adopted as numerical data was created that can be analysed through deductive reasoning. (Bryman and Bell, 2011) In this case student learning can be evaluated from the time-based activity. A mixed method survey of Likert and short answer questions (Allen and Seaman, 2007) was designed to gather focused responses from the students' reflections.

However, it is noted that the Likert five possible responses provide an indication of how much they personally strongly agree, agree, neither agree or disagree, disagree, or strongly disagree. The data analysis of the range of responses is opposite to interval analysis. The advantage of adopting the Likert approach is essentially that it is a closed question approach that promotes respondents to reflect and respond (Reja et al., 2003). The short answer open questions provide the opportunity for the respondents to express their premedicated and spontaneous reflections of the learning (Reja et al., 2003). Both the closed and open questions were designed to enable the respondents to answer without any influence or bias imposed by the researcher (Reja et al., 2003).

Quantitative Results and Evaluation

A survey has been conducted to qualitatively and quantitively assess the students' depth of learning and provide analysis of the level of practical engineering learning. In doing so, the survey questions are aligned to the Engineering Council's AHEP 4.0 learning outcomes in order to evaluate the extent to which its principles are fulfilled. Findings from the analysis of a total of 25 responses are as follows:

Formative vs Summative

Considering the formative nature of the session, the questions investigated the various effects of grading on students' performance, engagement and motives. The results revealed that the majority of students believed that the fact that the session was not graded did not affect their level of attendance and focus. Although, a minority of three students believed that it did have a direct affect. The results were also indicative of the students' dissatisfaction of the level of engagement of their peers and group members. It was illustrated that the majority of students believed a graded session would push their peers to a higher level of engagement and focus during the session.

The results also show that the majority believed the nature of the session was not influential on their learning process and engagement. However, findings reveal that not grading the students has led to a higher sense of self-confidence, which has enabled the majority of students to express their ideas with less concern. Results have further showcased a higher willingness towards group working where the outcome is not graded. This is also in-line with the previous findings which illustrate an easier communication and expression of ideas in a formative setting.

Diversity, Inclusion

Overall, the students' response to the session and elements such as inspiring women in engineering, diversity and inclusion, was mixed. From the survey on being inspired to learn more about Verena Holmes, 12 out of 25 students gave a neutral response, while 8 agreed and 5 disagreed. This translates to almost 50% being more focused on the project itself rather than its origins of being inspired by Verena Holmes. However, on matters to do with equality and diversity, 10 out of 25 students were inspired to learn about diversity; 9 out of 25 students were neutral on this; and the remaining six were in disagreement. This proposes that Verena Holmes' contribution to the engineering world has shed light on this topic as it is an issue in today's world. On matters related to inclusive engineering, more than half of the students were neutral concerning wanting to learn more about inclusive engineering; while 8 were inspired and 4 were not. This shows how the students' views on inclusive engineering in this case were, for the most part, unbiased (Long III, 2016).

Table 1: Given the session was not graded, please indicate how much you agree or disagree with each statement

Question	Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree
I felt less anxious and could freely express my ideas	24%	52%	24%	-	-
It did not affect my learning process and engagement	16%	48%	28%	8%	-
I was more inclined to work with my peers rather than individually	16%	40%	40%	4%	-
I would have been more focused if the session was marked (module assessment)	-	12%	56%	20%	12%
I think my peers would have had a higher engagement if the session was being marked (module assessment)	4%	28%	32%	28%	8%
I was less motivated to attend this session	-	4%	28%	36%	32%

Table 2: The session was based around Verena Holmes' patent for the poppet valve, please indicate how much you agree or disagree with each statement

Question	Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree
Inspired your learning for this session	16%	32%	44%	8%	-
Inspired you and your group to innovate your own group solution	12%	40%	36%	12%	-
Inspired you to learn more about Verena Holmes	12%	20%	48%	20%	-
Inspired you to learn more about equality and diversity in engineering	16%	24%	36%	24%	-
Inspired you to learn more about inclusive engineering	16%	16%	52%	16%	-

Engineering Skills

There was a greater level of engagement with the technical, interactive and managerial aspects of the session. When it came to giving feedback on what skills were learned or improved, most of the responses concerned learning how to work as an individual and as a team but had little to do with the environment, security, diversity and inclusion. Perhaps the nature of the assignment had a hand in the results, by being more technically biased to the degree that issues that are equally important like the environment and diversity did not receive much attention. Another possible reason is that the students may be focussed on being accomplished engineers and are resultantly focussing on the traits that make them immediately employable whenever they take on their assignments. A survey was done by The Centre for the Advancement of Engineering Education among seniors and first-year engineering students and the intrinsic psychological motivation of being an accomplished engineer was found to be their main driver for taking the course (Sheppard et al., 2010). This may be backed up by the fact that when it came to what the students would do differently if they got to participate in the session again, most of the replies had to do with the technical side of the session. There was not much to do with diversity, inclusivity, or Verena Holmes herself. Secondly, when they were asked what advice they would give to the next academic year cohort, their advice mainly revolved around understanding and tackling the technical side of the assignment, but it did not have much to do with Verna Holmes herself, diversity, inclusion or the environment. Feedback on what should be improved was generally mixed, although the most common point of improvement mentioned was the time allocated to the session i.e. it needed to be increased. The list of skills in question are listed (Engineering Council, 2020) and the survey result regarding the developed skills are illustrated in Figure 5.

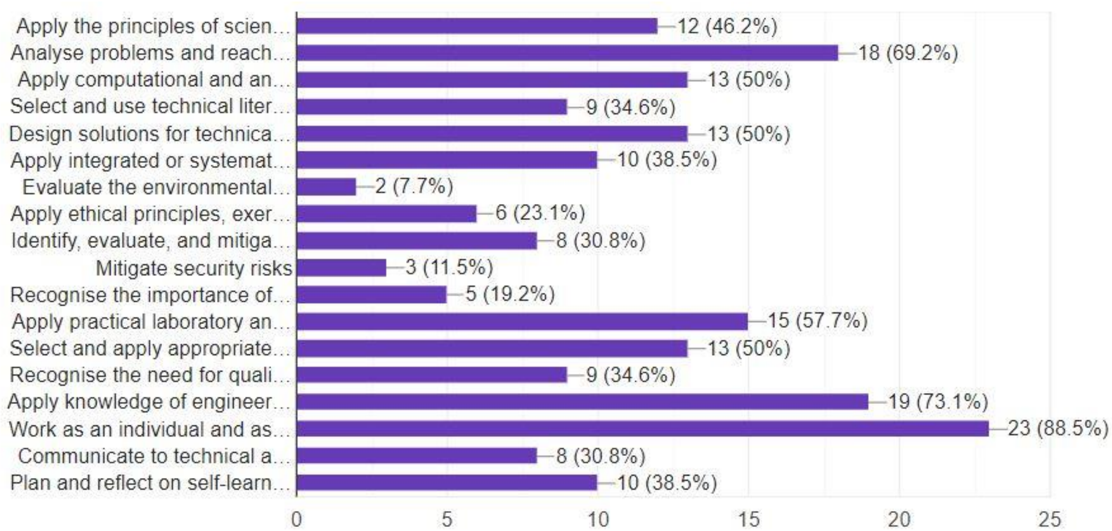

Figure 5: Skills that are adopted from the UK Engineering Council's defined fourth edition accredited higher education programme of learning for the first year of a degree (i.e. first-year technical engineering skills)

Quantitative Discussion

The survey aimed at highlighting Verena Holmes' work in promoting inclusion and diversity in an engineering education setting. As earlier stated, perhaps it would simply be better to address the issue head on instead of showing what people of different backgrounds can do when given the chance, because that point was missed for the most part. Moreover, highlighting the importance of diversity and inclusion may help students view this with a greater level of importance. It can show just how much the engineering fraternity stands to lose by limiting the inclusion of people based on gender, race or any other background that is currently maligned in the field. A similar exercise was carried out at Texas A&M University and was found to be successful, with 76% appreciating the fact that learning to interact with different cultures and backgrounds is one of the most important traits that will make them better engineers (TAMU, 2019). Furthermore, highlighting the importance of being an all-round engineer who does not only have the required skills to be a professional in the field and appreciates working with people from different backgrounds, but also appreciates the importance of conserving the environment and promoting health and safety will be highly beneficial to the students. This comes in light of the question in the survey where there was little cognisance of the environment and safety risks among the students when carrying out the assignment. It should also be recognised that these were first-year students, so these things can still be taught and integrated into their learning over time.

Conclusion

In conclusion, the students have demonstrated that they can handle the technical issues and tasks handed to them. They have shown that they can carry out technical research, understand it and use the information to formulate technical solutions and have them produced in ways that are useful to end users. However, in terms of recognising the efforts of the pioneers who were before them, there is not much recognition. This shows the importance of recognising how trailblazers such as Verena Holmes have had a hand in women entering the field of engineering and can be used as an opportunity to encourage any group of people to enter the field of engineering regardless of what challenges they may face and work to make a significant difference as she did. Further work should be done to encourage this among the students as they are the next generation of engineers.

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