DEVELOPING ENGINEERING GROWTH MINDSET THROUGH CDIO OUTREACH ACTIVITIES

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ABSTRACT

CDIO based learning is established around student-centred pedagogy where active learning method is incorporated, and project-based hands-on skill is fostered with academic facilitation. To support the development of the new School of Engineering, Technology and Design, the academic team of Canterbury Christ Church University has been promoting engineering courses through creative project-based activities at High Schools as a part of the university's outreach. These sessions were aimed to help students realizing how complex, industry-standard engineering product can be designed from a simple idea. At the beginning of each activity, students' response was usually very low as only a few students were genuinely interested in pursuing an engineering career. However, the confidence level of the students had been boosted through CDIO activities where they conceived an engineering problem, therefore designed and developed feasible engineering solutions of it. Feedback from students revealed a list of socio-economic barriers that were preventing students from considering engineering, such as; fear of mathematics; not having enough practical knowledge; hands-on skills. Students also perceived that they should be extra-ordinary or super-intelligent to pursue an engineering course. According to a recent UCAS survey, the number of students admitted to the graduate degree course (especially engineering) is decreasing. Even after enrolling into a graduate programme, the student retention ratio is very low, either they left the course or choose another career option. In this paper, we have identified the areas for improvement in the outreach activities to support the growth mindset of students, myth-busting who can be engineering professionals and develop student confidence in their ability to be a future engineer. Once they recognize their strength, they will be driven by their passion rather than pressure. This paper also highlights the advantage of utilizing CDIO activities in the outreach to change student's mindset, successfully promote engineering.

KEYWORDS

Outreach, CDIO, project-based learning, growth mindset, STEM

INTRODUCTION

This paper aims to show how the student's perspective can be changed following the CDIO activity at schools and colleges. Most of the universities in the UK take part in outreach activities for promoting career in STEM subjects (Millar, et al. (2019)). Canterbury Christ Church University has been working in collaboration with local schools and BTEC colleges in

the south-east region of UK for nurturing future aspirants in engineering and medicine. So far, we had an opportunity to engage with seven high schools and one BTEC college. After delivering these outreach activities, we have identified the key issues that constrain student's mindset to pursue an engineering career. After a thorough analysis, we believe CDIO based activity is one of the best solutions to overcome these issues.

Before starting the CDIO session, a small survey was usually conducted among the students to know their mind-set about pursuing their career in engineering in future. It was quite surprising to see that most of the students were reluctant to see themselves as a future engineer. Out of those students, only 10% were interested because of their family history, either their ancestors were engineer or they were influenced by their family members or relatives. Only 5% of the students were genuinely interested to pursue engineering course. After further analysis of student feedback, there were several misconceptions about engineering courses. Most of the students thought engineering was difficult and strenuous to undertake, because it is all about mathematics, engineering courses required investment, time and hard work which may lead to failure. This could lead to students dropping out of their studies mid-way incurring financial debt, in turn, deprive them of having high-quality employment and life. Also, they used to consider engineering as one of the monotonous subjects which may hinder their personal and social life.

Our observations are consistent with Hochanadel & Finamore (2015) who reported that the most common underlying reasons why the majority of students were not confident enough to pursue engineering was their fear of mathematics, possibly because of their prior experience and mindset. Students were under impression that they need to be super intelligent to pursue an engineering career and they believed that intelligence is something come with birth and they cannot do much to change that.

All these socio-economic problems suppress the interest of engineering in most of the students. In the present scenario, the number of students admitting into degree course is reducing. Courses related to the STEM subjects are affecting the most, therefore the numbers of future engineers and technicians all around the UK is decreasing day by day. Following a recent UCAS survey (HESA, 2018), it was found out that the number of students admitted in a graduate degree course (especially engineering) is decreasing. One of the present statistics (Dusty Baxter-Wright, 2018) shows that even after enrolling into graduate programme, students leave the course in mid-way or chose another career.

Several researches have been trying to enhance the engineering pedagogy and learning experience, through project-based learning (Petersen & Nassaji, 2016), problem-based learning (Savery, 2006), CDIO (conceive-design-implement-operate) based approach (Ye & Lu, 2011), experimental learning (McDonald & Spence, 2015) and so on. In project-based learning, students are actively engaged in real-world projects during the course. At the end of the course, they can demonstrate their knowledge by giving a presentation. Students can develop critical thinking about the real-world problem, collaboration with fellow friends, team-work with a meaningful discussion and deliver an idea with proper implementation. In problem-based learning, students are focused to learn subjects through the experience of solving open-ended problems. This type of learning process encourages students to acquire new knowledge with group work and critical appraisal through literature retrieval. CDIO based learning is also one kind of project-based learning, where modules are developed around a CDIO based project. This type of project helps them to conceive an idea, design a solution to implement that idea and operate the solution to verify its working principle for further modification and

improvement of the project. Experimental learning is another form of learning where students learn through the reflection of previous experience. It also promotes hands-on skills and supports the students process their learning each quadrant of Kolb's learning model (Konak, Clark, & Nasereddin, 2014). The main theme of all these learning approaches is based on student-centred pedagogy where project-based learning implementation.

Out of all these methods, CDIO was found to be quite helpful to motivate the students in outreach in terms encouraging them to pursue their career in STEM subjects because we believe it would combine the rest of the other methods under a single platform. CDIO is a four-stage engineering project framework. In the first stage, conceive helps students to develop new ideas to solve a problem assigned to them, do background research, come up with a feasible solution. In the next stage, students plan the design and develop the solutions. Students would fabricate or manufacture the design and implement the solution in the implementation stage. In the final stage, students will evaluate the challenges and issues of the developed solution and provide critical in-depth reflection for further improvement. Using CDIO based activity, students would be benefitted from every aspect of several learning approaches such as project-based learning, problem-based learning and experimental learning. For an example conceive and design stage of CDIO reflects the problem-based learning whereas implementation stage of a design idea shapes the project after several iterations- which is nothing but project-based learning, and experiment learning is all about operating it to identify the areas of improvement through future modifications.

METHOD OF OUTREACH ACTIVITY

The outreach activity was organised in four segments (). In the first segment, recent innovations in science, engineering and technology were shown to students, made them familiar with the real-world engineering problems and its probable solutions. Students are usually fascinated by these amazing innovations and ideas. In the next segment, few PowerPoint slides were presented consisting of some industrial standard products followed by a couple of hobby projects, sharing the similar engineering concept.

In the next segment, the fundamental conceptual link between those complex engineering products and hobby projects was explained among the students, also described how those hobby projects can be transformed into complex, industry-standard and commercialized products with appropriate technical expertise and hands-on skill. In the third segment, few CDIO activities were carried out to enhance their interest level through active participation in designing and developing a project. For example, a simple project that needs to be designed by students within a time limit or they need to program line tracking LEGO robots. This type of project helps them to conceive an idea, design a solution to implement that idea and operate the solution to verify its working principle. In the last segment, feedbacks from students and teachers were collected to evaluate the potential of the CDIO activity and recommendations were taken on board for making it more effective.

Figure 8. Four segments of outreach activity

Presentation on Recent Innovations

This segment was aimed to show students the conventional as well as the cutting-edge research projects in engineering and technology all around the world. Sometimes, students are unaware of current innovations, therefore this approach would make them familiar with those innovative projects and increase their interest level in STEM subjects. Also, it showed the transition of the scientific world from earlier days to the modern era where students can contribute and become a part of it. Those projects were divided into two categories (Figure 9); one is the conventional industry set-up that has been running for the last two decades and other is the emerging cutting-edge technology that has been implemented to solve specific problems. First two examples were conventional car manufacturing industry and four-stroke engine. In-car manufacturing industry, conventional serial robots perform most of the functions and the four-stroke engine is a conventional engineering product, one of the finest examples of mechanism and design.

Next two examples fall into the category of cutting-edge research such as exoskeleton and drone-based car. Exoskeleton or wearable skeleton is normally people-oriented robots designed to be worn for training and assistance. These robots are designed based on the function and shape of the human body so that users can control intuitively. Exoskeletons can assist in walking, running, jumping or even lifting objects one would normally not be able to. Drone is one of the most trending topics in the current scenario, there are several applications of it; staring from medical purpose to use it as an aerial ambulance or to transfer medical equipment like blood quickly. It could be used as public transport to avoid heavy traffic. Also, there is plenty of applications for surveillance and military operation in the defence sector.

a. Car manufacturing industry

b. Four/stroke engine

c. exoskeleton

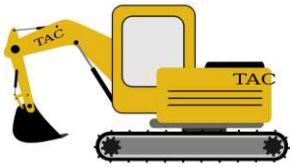
d. Drone based car (Fildes & Yang, 2019)

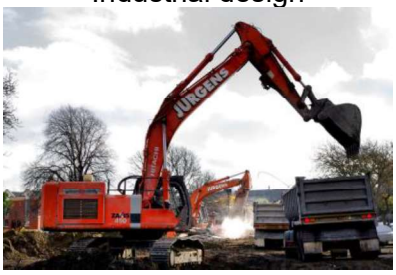
Figure 9. Innovative products (conventional and cutting-edge technology)
(all the pictures are licenced for reuse)

Creating the Pathway from a Hobby Project to Industry-Standard Project

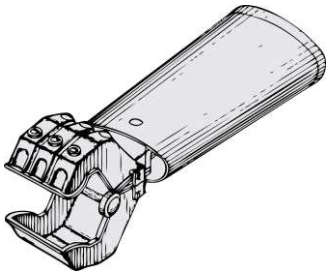
This segment is the most important and was designed to enhance the confidence level of students. We have chosen three different types of projects for the students.

Hobby project | Simplified design | Industrial design

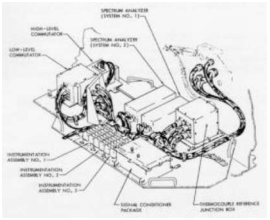




Hydraulic digger project



Bionic hand project



LEGO-based unmanned vehicle project

In each project, the left-most picture shows a basic hobby project which is comparatively easy to design for school students. The middle picture shows the engineering concept behind all those projects. The right-most picture shows the advanced commercial products which share similar engineering principle with the hobby one. In the first project, a hydraulic digger made from plywood was shown to students, which is the basic design of an industrial digger. Therefore, students will be familiar with the conceptual design framework of an industrial digger. The next project was about a paper-based artificial robotic hand which is a simplified version of a bionic hand and the third project showed a LEGO robot which could be transformed into an unmanned ground vehicle. In all cases, the basic designs were shown to students in the beginning. After that, the advanced designs were displayed along with the engineering principle to make them realised the link between those basic and advanced designs. This whole segment would create a pathway that guides students to reach from a basic idea to an advanced design model.

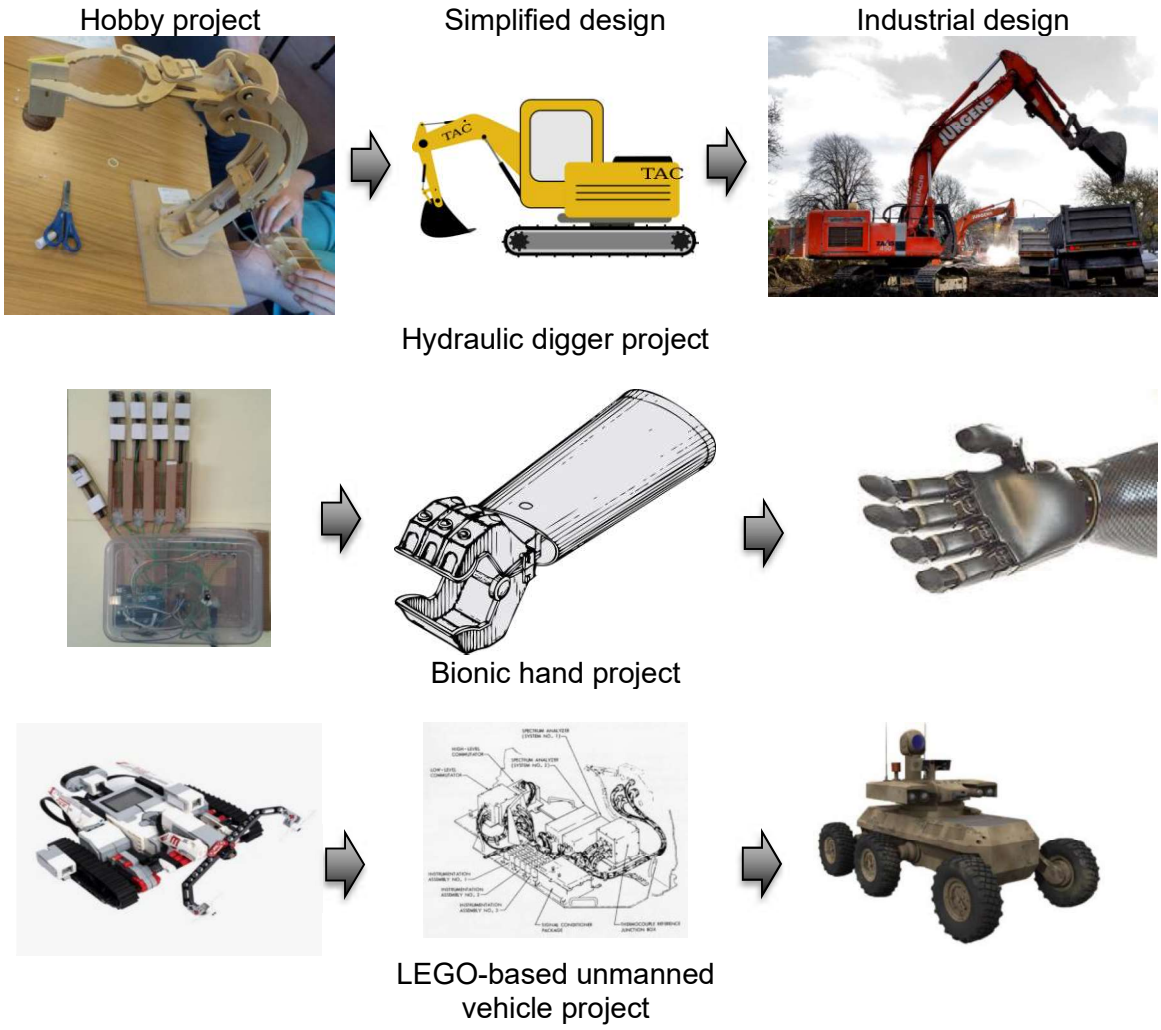


Figure 10. The pathway from hobby to industry-standard project (all the pictures are licenced for reuse otherwise taken from CDIO sessions run by CCCU)

CDIO Activity

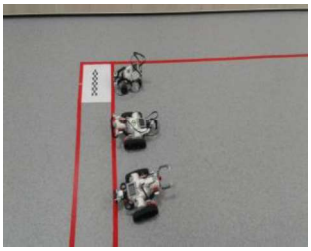
Following the previous segments, three CDIO projects were configured (Figure 4) where several technical and professional skills (Table 1) were nurtured among the students. The first project was the design and development of a hydraulic digger where students were supposed to construct it from hard plywood and screws. For implementing hydraulic actuation system, small syringe had been used with water. This project was designed to show the basics of hydraulic actuation and holding mechanism in the simplest way; therefore, students can easily conceptualise its underpinning engineering ideas.

The other project was making of an artificial robotic hand from generic items such as hard paper, paper straw and cotton string. The project was given to students to put them in a real-life scenario, for example, if they need to make an artificial hand for amputees, what would be their approach? how they would design it so that the functionality of artificial hand will be the same as a real human hand? Students worked in a team to complete the task. The Lego Mindstorms robot was also included as a CDIO activity. Since those robots are easy to

construct and program, those activities are suitable for school students. Students were supposed to program it in a way so that it would follow a certain track avoiding all obstacles. This project was interesting for students because they need to calculate the speed, power, rotation, direction angle to decide the trajectory of LEGO robots.

Hydraulic digger

Articicl robotic hand



LEGO Mindstorm robots

Figure 11. CDIO activities
(all the pictures are taken from CDIO sessions run by CCCU)

Table 1. Three CDIO activities

Type of activity	**Description**	**Technical skill involved**	**Professional skill involved**
Artificial robotic hand	Introduction to the design and development of an artificial robotic hand. This workshop will provide a great opportunity for students to learn about different engineering aspects such as mechanical design, actuation system and controlling circuit.	Mechanical design, analytical skill, actuation system, electronics	Teamwork, time management, collaborative work, critical reflection
Lego Mindstorm robot	To improve critical thinking, problem-solving and collaboration skills, an engaging and inspiring STEM activity is designed based on Lego Robotics technology. Students will be introduced to the programming concept and path planning skills of the robots. In the end, Students will work in a team and they will be provided with the Robots, iPads and short training to complete a Robotic race.	LEGO robots, basics of programming, simple mathematics, computer apps	Teamwork, time management, collaborative work, critical reflection
Hydraulic digger	Introduction to the design and development of a hydraulic digger. Students also will gain knowledge of 3D modelling using CAD software. In the end, they will get the opportunity to build their hydraulic arm using the provided hydraulic kit.	Mechanical design, CAD design, mechanism, hydraulic actuation	Teamwork, time management, collaborative work, critical reflection

All these CDIO workshops provided a great opportunity for students to learn about different engineering aspects such as mechanical design, actuation system and controlling circuit for obtaining a technical solution to a genuine engineering problem. They were also able to analyse the core engineering principle behind the project and their hands-on skill was enhanced through the engaging activity. Also, they got the opportunity to understand the advantage of teamwork because an ultimate engineering product requires multidisciplinary

engineering knowledge starting from electronics, mechanical, computing, electrical and design. Students can develop their engineering competency through producing and implementing innovative and creative ideas.

These outreach activities were usually organised in career fair weeks where students came to know more about engineering, its curriculum and future aspects. Table 2 gives the statistics of the total students who participated in these outreach activities.

Most of the students were from year 12 as they were on the verge of choosing their career. Whereas, we also had students from year 7, 8, 9 and 13. From the statistics shown in Table 2, it was very inspiring to see the female to male ratio, it showed that a significant number of girls students participated in those outreach activities which proves that girls are equally interested in pursuing an engineering career.

A typical outreach activity was carried out on average from 50 mins to 1.5 hours depends on the type of activity, year group of students and number of students. Out of the total time spent, CDIO activity was typically carried out on average from 40 mins to 1 hour.

Table 2. Statistics of outreach activities run by us from May 2019 to December 2019

Date	School name	No of students	Female: Male ratio	Year	Total time for outreach	CDIO activity Time
03/05/19	Skinner Academy	26	11:1	12	1:5 hours	1 hour
18/06/19	Folkestone School for Girls	15	All girls	7 & 8	1.2 hours	1 hour
18/06/19	Ursuline College	15	All girls	7	1.2 hours	1 hour
18/06/19	Spires Academy	15	13:2	9	1.2 hours	1 hour
16/07/19	Dover Grammar School for Girls	14	All girls	8	50 mins	40 mins
		74	All girls	9	50 mins	40 mins
		62	8:3	12	50 mins	40 mins
19/07/19	Sandwich Technology School	10	All boys	12	1 hour	45 mins
04/11/19	Leigh UTC College	35	2:3	12	1 hour	45 mins
		35	2:3	13	1 hour	45 mins

Feedback and Critical Reflections

To enhance the involvement level of students and to know their present career perceptions, few questions were raised such as what they know about engineering, how many of them would like to pursue engineering as a career? Few questions are listed below in Figure 12. The advantages and constraints of pursuing engineering and technology as a career were also explained to them so that they would be clear about their choice. Few technical questions were also asked to students to see their confidence level in dealing with an engineering project. In the end, several enquires were raised from students as well as teacher, few of those queries were listed in Figure 12. Most of the queries from students were all about engineering and its prospects whereas teachers mainly asked about the infrastructure and facilities available in the School of Engineering, Technology and Design at CCCU.

Questions asked by instructor from CCCU
What do you like to be in future or what type of career you want to choose in future and why?
What do you think about engineering?
How many of you are interested to pursue engineering as a career?
How many of you are confident enough to make this type of project? (pre and post CDIO activity)

Questions asked by students and teachers
How math is involved in engineering?
What are the career options available after pursuing engineering?
What are the facilities available at CCCU?
And, several questions about the School of Engineering at Canterbury Christ church university

Figure 12. Questions raised during outreach activities

We realised that students always want to see some innovative engineering projects instead of complex mathematical equations and calculation. Due to our prior experience, most of the sessions had been planned on hands-on skill where students were supposed to do some activity by developing some projects. Feedbacks were taken from students after each segment to understand their mindset.

For instance, after showing those recent innovations, we wanted to see the attitude of students towards solving a problem, so we inquired how many of them were confident to make those kinds of product if they get an opportunity provided with enough resources and technical expertise, only 25% of the interested students showed a positive response. Their opinions about engineering were taken into consideration and appreciated positively. However, the student's response has been increased drastically (up to 75%) after executing these CDIO projects. It was found that the engagement ratio of students in outreach was also increased by 91% after doing the CDIO activities (Figure 13). Also, the number of raised questions from students was increased by 64% post activity, as shown in Figure 13. At the end of the session, a greater number of students became interested to pursue an engineering career.

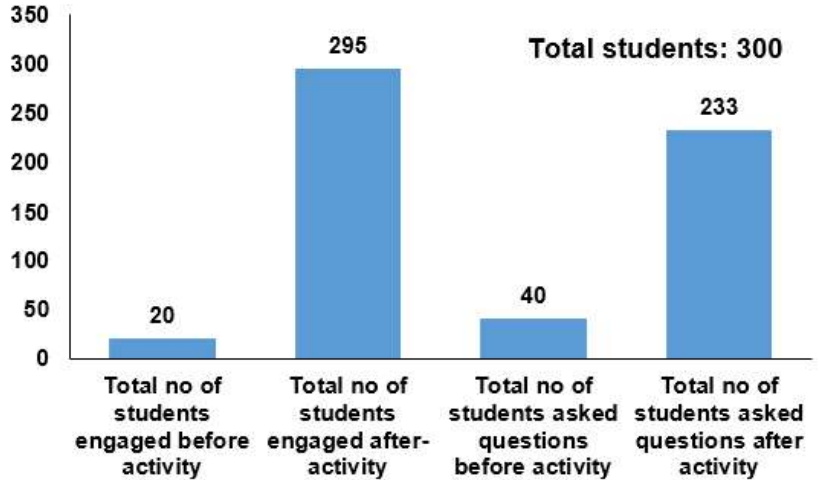


Figure 13. Engagement of students in pre and post CDIO activity

Few positive feedbacks from coordinators of those schools are listed below as an example to showcase the efficacy of implementing CDIO activity in outreach. The feedback has been anonymised to ensure the anonymity of the students and good ethical research practice.

Example 1

"*Thank you from xxx Grammar School*
Teacher A
XX/XX/2019

Can I just say a huge "Thank you" to you for your wonderful support of our students at our recent and inaugural XXX Careers Fair.

The feedback we have had from students has been universally positive and I hope that you also enjoyed interacting with our young people. Such events only work when people such as you give so generously of your valuable time and we are hugely appreciative of the efforts you have gone to on our behalf…."

Example 2

"*Thank you from xxx Tech School*
Teacher B
XX/XX/2019

I just wanted to send a thank you for coming in to speak with our students. These opportunities are always valuable and so insightful for our Year 12 students as they enter year 13 and consider their next options. I have received great feedback from the students…"

Example 3

"*Thank you from xxx College*
Teacher C
XX/XX/2020

Just wanted to take this opportunity to thank you for an amazing day. The year 12 and 13 students were captivated by your workshop today. All the teachers that attended gave me glowing reviews of your sessions and the students walked out of the lecture theatre motivated and inspired…."

CONCLUSION

"Student should be encouraged to think, to doubt, to communicate, to question, to learn from their mistakes, and most importantly have fun in their learning" (Richard Feynman)
Following these outreach activities, it has been proved that implementing CDIO activities in outreach could potentially change a student's mindset towards engineering courses. We have received several positive feedbacks from students as well as teacher about these CDIO activities. Responses from students demonstrate that their confidence level was enhanced and their attitude towards solving a technical problem has been changed. All those activities aimed to make them realised that studying engineering is all about to conceive those innovative ideas blending with subject knowledge to achieve the proficiency level. These CDIO activities influenced most of the students and engaged them in the engineering theme. The strategy consisting of four segments starting from introducing innovative engineering project to

designing the project could be a game-changer for bringing back students to the STEM subjects. The experiences gained through these CDIO activities can even improve the learning strategy and could be implemented in the engineering curriculum.

Engineering subjects are typically underpinned by their prior concept of physics and mathematics where students might struggle. However, students should have a chance to cultivate their hands-on skill as well, which would help them to have a better understanding of STEM subjects. The learning environment should be enhanced to change the mindset of students to boost their confidence and motivate them to undertake engineering career.

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BIOGRAPHICAL INFORMATION

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