Innovative chemistry education: An alternative course models in the disruption era

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Abstract. In the era of IR 4.0 and society 5.0 is existed the global disruptive in every aspect of human life even in the education world. This study literally stated the innovation course models in chemistry education. The innovative learning models directed to be able to develop the ability of students’ use of the ICT and work together and communicate with one another in chemistry learning, especially in laboratory activities. The study of Biochemistry showed that laboratory course should be done before the theoretical course. Study of LPBSOURA in Organic Synthesis course using a retrosynthetic approach shows that students applied their concept mastery of several courses related before, green chemistry and skilful in software application in predicting target molecule. The studies also show that innovative learning models could improve students’ generic science, creative and critical thinking skills, using project based learning that can increase students’ thinking and skills to prepare them to face this era.

1. Introduction

The automation economy resulting from the technologies of the fourth industrial revolution (4IR), is changing the way we live and work. Information transfer is no longer the sole purview of institutions of higher education (HE). Information is everywhere and the collection of big data means we have brand new kinds of information. Good books are already changing to adapt their HE institutions as well as what nation are doing. HE is changing already as results of fast-shifting the types of employees and thinkers it demands. HE will have to change quickly in collaboration with governments and industry to respond to the automation of knowledge and production [1].

Talk of “Industry 4.0” (4IR) the changes that are happening now because human have finally developed the computing capacity to store massive amounts of data, which in turn can enable machine learning. The outcome of this is the development of cyber-physical systems (CPSs). Artificial Intelligence, robotics and the declaration of US National Science Foundation (NSF) 2006 would henceforth be a major area of research. The internet transformed how humans interact with one another, cyber-physical system will transform how we interact with the physical world around us. The design, construction and verification of cyber-physical systems pose a multitude of technical challenges that must be addressed by a cross-disciplinary community of researchers and educators [2].
How we live and work is being transformed by CPSs and other new technologies such as 3D-printing, the Internet of Things (IoT), block chain, and artificial intelligence. Many new jobs that will exist even ten years from now and the well-paying jobs will involve creativity, data analytics, and cyber security, as there is currently a global dearth of talent in this area.

Education through traditional institution is still important, but their collaboration with industry and governments need to be much intense. Universities still need freedom in their research and many do not want their research agendas and curriculum dictated to them, but more communication is always a good thing. Financing from industry and government to upskill existing population is also essential. It is important to develop critical and creative thinking in every course in the higher educational system. There are many difficult things should be solved through problem/project-based learning.

In the 4IR immerging the disruption era where higher education should be changed in their business. They should be innovating like technology that changing to face of business. The higher education have to change the technology using to customer oriented and should not only be regulated by the government. Learning in higher education should be research based using students’ centred learning and remote learning. At the end lecturers are need to use expertise mental model to get impactful yield. Learning should be creating an innovation culture with a growth mind set. The growth mind set included embrace, persists even with setbacks, see efforts path to mastery, learns from criticism, inspirational, therefore students reach continuous new levels of achievement to confirm greatest sense of free will.

ICT is the root of innovation. Human has extremely large computation power and data with very small cost. Based on it we should redesign all social system, although will not be accepted by many people, because they do not fully understand the power that is already available and accessible. Big data, AI, IoT and open data provides the concept of Society 5.0. Open data and IoT technology make everyone access variety of data. Big data and AI technology make everyone utilize or analyse data, make everyone open software for data analytics that enable them to utilize data in their own, then they will create a smart city/district or virtual city. The goal of urban-based social system is every one participates actively in social solution development, society allows mixed utilization of cross-domain data, people change acceptability of sharing their data and belongs. In educational digital’ data revolution is also changing education of higher education in university that expected to increase at elementary and high school levels within next decade. Professional education especially teacher education will also be looking to ICT for new principles, methodologies, and tool for education. There also needed learning records e.g. personal learning records as well as health records. Education data science shows also educational data engineering, human engineering and AI as Cognitive Science and Brain science. Learning science including pedagogy and psychology, educational engineering included computer science and data science. In Japan it began in 2013 project [3].

2. Condition at higher education in society 5.0
Society 5.0 defined as a society of intelligence in which physical space and cyberspace are strongly integrated. The term first appeared in Japan in 2016. The term used by Japanese Government’s Council for Science, Technology, and Innovation (CSTI). Society 5-0 emerged from the hunter-gatherer society, the agricultural society, the industrial society and the information society. This is a new type society where innovation in science and technology occupies a prominent place, with the aim of balancing social and societal issues that need to be solved, while ensuring economic development. This approach is opposed to the proponents of decline. The improvements are from hunting society, agrarian society, industrial society, information society to super smart society or ‘5.0 society’. The plan has been brought forward as a model for a wide range of stakeholders including the university environment as co-build the society of tomorrow to make the most favourable country for innovation. In France the innovation began in 2016 on ecological mobility to 2020 that 30 % decrease in CO2 emissions of new vehicles manufacture.
The society 5.0 including industry 4.0 and cybernics has changed lifestyles, with the appearance of
city 3.0 (rational society) that society employs information and communication technologies 2.0 and
defines humanity 2.0 (civilized society) [4].

Higher education in Society 5.0 will be encouraged to review their educational programs to provide
the kind of education that many students will need in the future for example STEAM and design
Thinking. Build up the design thinking by developing students HOTS (critical thinking, creativity
thinking, reflective thinking, etc). It also provides the transition to a framework that can provide across
departments liberal arts that are studied in common by all students and specialized fields (e.g. human
and social sciences, STEAM, healthcare, etc) that are selected by students. In addition to the
development of leader and expert AI human resources majoring in STEAM, human resources
majoring in the human and social sciences will be developed to acquire needed AI-related knowledge
through studying both the humanities and sciences. Human expert resources in AI that should be
developed also at colleges of technology and especially training college, not only universities [1,5].

3. Innovation in chemistry learning at higher education

The emergence of a changed in the direction of international development from the Millennium
Development Goals (MDGs) towards Sustainable Development Goals (SDGs), requires every higher
education to respond to this changed [6]. The basis for this change in the MDGs, the direction of
development aimed at resolving problems at that time, whereas in the SDGs the direction of
development to be aimed in a sustainable manner. Development must also consider the direction of
education in the future. Substantial changes in the science and technology curriculum in each
institution needed to respond to this direction. Innovations in the chemistry curriculum carried out
through a green chemistry program that combines chemistry, biology, environmental science that
enables students to engage in real environmental problems, such as synthetic fuels, bioplastics and
toxicology, and to train students in techniques to reduce pollution. Higher educational response in
society 5.0 has done by restructuring institutions with developing new science programs that are
interdisciplinary in nature and generating innovative learning that is able to develop 21st century
skills. This is a challenge for the development of the quality of learning in higher education. We need
to improve the quality of learning that can support improving the quality of student thinking, learning
needs to be directed at innovative learning models. The innovative learning provided aims to be able
to be a provision for students in their daily lives and in the world of work.

One of the courses that chemistry teachers need to take is biochemistry courses. The characteristic
of Biochemistry course has abstract and related to socio scientific issues (SSI). Several studies have
developed biochemistry course using SSI, such as the use of blood sugar contexts to explain
carbohydrate metabolism, influenza and HIV to explain DNA replication, herpes to explain membrane
transfer, and sports contexts to explain microscopic biochemistry concepts [7–11]. Meanwhile, latest
research developed a biochemistry course using the context of browning potatoes to explain enzyme-
substrate interactions [12].

The development of innovative biochemistry course needs integrating theory and practice. Through
this integration, students have benefit from discovering the relevance of theoretical and practical
activities, obtaining intact biochemistry content, and improving students' higher order thinking skills
(HOTs). The integration of theory and practice would foster challenging learning for students [12].
Knowledge transfer will be more real because students directly observe abstract phenomena. The pattern of integration of practice to theory will help students construct their knowledge based on direct
experience that has been received, while the pattern of theory to practice will help students in the
elaboration of knowledge gained through theoretical activity [13]. The integration activity lead to
active learning, where students will be more involved in learning through given problems.

The best integration of practice to theory pattern is using problems as the initial unit. This pattern
will lead students to solve problems independently through inquiry (mini research). The skills that can
be developed with this pattern are critical (CT) and creative thinking skills (CrT) together. In addition, these activities will also develop communication and collaboration. The application of integrated
biochemistry course can improve students’ CT dan CrT simultaneously with a percentage of 50% [14]. Indicators of CT that appear are observing and considering the results of observations, while CrT that emerge were fluency, elaboration and originality. In practical activities, critical and creative thinking skills built when students analyse and determine problem based strategies, create procedures, and analyse of results. Analysis of % N-gain of students' CT and CrT by comparing patterns of integration between practice to theory (P→T) and theory to practice (T→P) showed in Figure 1 and 2.

Based on Figure 1 and 2, the pattern of P→T more enhance CT and CrT than patterns of T→P. The pattern of P→T and T→P were developed by using problems as the initial unit of learning. The problem “browning reaction on potatoes” is authentic and contextual problem that solved by students. The existence of these problems will motivate students, develop their curiosity and actively participate in learning to get answers. Students in pattern of T→P receive knowledge based on direct instruction and students in pattern of P→T receive knowledge through investigation, laboratory activities and discussion. This activity facilitates students to interact in group discussion and creates a platform for students to experience an environment that is conducive for CT and CrT to grow [15,16]. These improvements of have accommodated by the process of interaction, reflection, and feedback in the problem.

Other learning innovation that carried out through development and implement organic synthesis in laboratory learning program models in the form of the Laboratory Project Based Organic Synthesis
Using Retrosynthetic Approach (LPBSOURA). This is due to the fact that the study of the difficulties of students in answering the problem of synthesis of organic compounds [17]. Even students lack the generic science skills, which influences the students' understanding of the concepts of the implementation of Organic Chemistry synthesis [18]. LPBSOURA is a form of inquiry approach, which can increase student involvement in laboratory learning activities, in order to develop thinking skills their critical and generic science skills [19, 20,21]. In this learning model, supported through the use of software that helps students analyse the structure of synthesized organic compounds to be able to find the starting material compounds needed [22, 23, 24,25]. It also combines with project based learning in the laboratory based on the synthesis of organic compounds using a retrosynthetic analysis approach for students.

This learning is the innovative model in learning model. In addition, LPBSOURA learning also directed to increase in generic science skills and critical thinking. In the stages of determining the characteristics of the target molecular compound that should be synthesized, students should make hypotheses. A retrosynthetic analysis of the target molecular compound carried out using the Marvinsketch software media (example in Figure 3). It gives the modelling of molecule and prediction of energy minimize. While in the stages of planning a strategy to test the hypothesis and design the synthesis of the target molecule compound using Reactor ChemAxon software.

![Figure 3](image_url)

**Figure 3.** Modelling and calculation of organic molecule of using Marvinsketch ChemAxon.

Based on Figure 3, we can see the result of using Marvinsketch ChemAxon to model and calculate the Organic molecule. It helps students to figure out the shape and structure of molecule and can predict the stability of the molecule. Figure 3 shows the achievement of students in generic science skills.
Figure 4. Result of % N-Gain for generic science skills.

Figure 4 shows the generic science skills of students in all indicators have increased. For generic science skills of students, the highest % N-Gain (70.90%) is the indicator of logic inference and the lowest is in constructing concepts (48.60%). The % N-Gain results show an increase in students’ generic science skills after the implementation of the LPBSOURA learning model.

Figure 5. Result of % N-Gain for critical thinking skill.

The critical thinking skills on all indicators show improvement like in Figure 5. The highest critical thinking skills of % N-Gain students (88.56%) on the indicator provide a simple explanation in analysing the argument, while the lowest at providing a simple explanation to consider the credibility of the source (45.41%). With this it is known that LPBSOURA learning model is effective improving of students’ generic science skills and critical thinking skill [25].

The results of LPBSOURA shows that learning in chemistry education in era of Industry Revolution 4.0 and Society 5.0 should be have the innovation, because it can help students to combine all the IT to learn in chemistry. The innovative model of LPBSOURA also combines the IT with the ability of students to learn in project in laboratory in groups. The project gives opportunity for students to apply the concepts that they have by using the software. The project in laboratory makes students can always prove their project by doing hands on project laboratory and they still develop the ability to communication and collaborate with other students.
4. Innovative chemistry in pre-service teacher training

The role of the world of education must always be dynamic and responsive in facing the challenges of development and times. This effort must certainly begin at the school level and the preservice teacher level. Based on national policies in the field of education, such as equal distribution of learning opportunities, increasing the relevance of education according to development, improving the quality of education, and the effectiveness of education, the teacher is professionally located at the central point. To become a chemistry teacher, one must take education at a teacher educational institution. The challenge of prospective chemistry teachers will face in developing quality learning is the rapid change in the flow of technology. This is a challenge for chemistry teachers in developing technological capabilities and contexts that are relevant to changing times.

In this era of IR 4.0 and the society 5.0 prospective chemistry teachers need to learn ICT because they have to act as facilitators for their students who can bridge various information and technologies that continue to develop. But it is also known that the use of ICT media and information and technology need to be followed by meaningful learning such as hands on learning in the laboratory. This is due to the occurrence of misconceptions related to the learning material provided [26]. For this reason, it is necessary to have an understanding of the concepts followed by student skills to be able to apply them through activities in the laboratory. Laboratory activities can also be integrated with the use of ICT in learning. For this reason, students’ prospective chemistry teachers are expected to be agents who prepare students to have thinking skills that are in accordance with IR 4.0 and society 5.0.

Characteristics in chemistry learning have attributed mainly abstract, unobservable, particulate basis, and need quick transfer across the three identified level of chemistry understanding such as the macroscopic, sub microscopic and symbolic. Students are often required to make predictions about relationships between continuous variables and to quantify such relationships. ICT have important role in chemistry learning for computerized molecular modelling, computer graphic software and simulated chemistry laboratory. This is very useful when they create reaction model, plot graph, calculate data, using 3D animations, and prepare their learning activities in chemistry teaching.

5. Conclusion

In order to improve the ability on students’ concepts mastery in the era of IR 4.0 and society 5.0 there are needed interactive learning models. This learning model can combine hands on learning with the use of ICT that has developed in this century. In addition, innovative learning models directed to be able to develop the ability of students to work together and communicate with one another. The laboratory course should be done before the theoretical course in higher education. The innovative laboratory course should be green chemistry and make relation interconnects with other theoretical courses before. To make laboratory innovative courses interesting it should be started with sociocentric issues. The results showed that this innovative learning model could improve students' generic science, creative and critical thinking skills.

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