Lok Kwan Tse
Bachelor of Visual Arts

The mind contemplating "light and refraction" and "light and shade":
Blending art and science in education

Dissertation for master's degree in
Glass Art and Science

Advisors:
Robert Wiley
Christopher Auretta

Jury:

Presidente: Doutora Inês Alexandra Ramalho Coutinho, Professora Auxiliar, Faculdade de Ciências e Tecnologia da Universidade NOVA de Lisboa
Vogais: Doutora Márcia Gomes Vilarigues, Professora Auxiliar, Faculdade de Ciências e Tecnologia da Universidade NOVA de Lisboa
Doutor Richard Craig Meitner, Investigador, Faculdade de Ciências e Tecnologia da Universidade NOVA de Lisboa

FACULDADE DE CIÊNCIAS E TECNOLOGIA
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ABSTRACT

Art and science often seem or are presented as being dichotomous. Accordingly, art is subjective whereas science is objective. Thus, too, art is about irrational feelings whilst science concerns itself solely with rational information. In fact, rather than see them as polar opposites, we should see them as different manifestations and incarnations stemming from the self-same source of human creativity. From what we know of the early days of human existence, as revealed by anthropology and the social, human and natural sciences in general, humans have always been involved in art-making and experimentation. From cave paintings and the mastery of fire-making through to pottery, both domains, i.e., science and art have evolved together as human culture has progressed. With the Industrial Revolution, we began to teach specialisation in one domain or the other and, entrenched within these now-divorced knowledge domains, to specialise even further into ever more specific fields. Thus, the specificity and inner gravity, so to speak, of highly specialised knowledge further widened the gap between the domains of art and science. As a result of this phenomenon of specialisation, art and science drifted apart in academia, finally crystallizing into separate subjects taught, in turn, by specialised individuals. This phenomenon of specialization and exclusionary knowledge practices ultimately steered me in the direction of art, thus leading me further away from the domain of science. Fortuitously, glass making opened a path for me to get to know science better as well as ignited my scientific curiosity. The artist and the scientist's creative life are made up moments of epiphany: moments which have led me to a more nuanced and deeper level of personal achievement and satisfaction. Specifically, my epiphanic moment has allowed me to embrace various science projects, producing glass and analyzing their properties, and engage with science to solve the technical problems arising during the process of art-making. Nowadays, I see science and art as related manifestations and both as the culmination of experiment and creativity. Both are, in their purest forms, deeply creative endeavours which bring us closer together as living, thinking beings and help us to transcend our limited, i.e., specialised perspectives. It is our belief that the merging of art and science in education will allow us to surpass the barriers of even the most deeply entrenched and dichotomous thought patterns.

Based on my experience of travelling between these two avatars of human creativity, the thesis reflects upon the value of, and need for, the reconciliation and reintegration of art and science in education. By engaging in transdisciplinary research, I have rediscovered myself and, consequently, discovered my ability to blend art and science. This thesis, in addition to my artwork, shows the results of my forays into art and science, i.e., the pursuit of mature creative, conceptual and pedagogical expression by way of distinct yet related modes of knowing and communicating, experimenting and creating.

Keywords: art, science, education, experience

RESUMO

As esferas de arte e ciência habitualmente se caraterizam como domínios separados. Segundo esta lógica, a arte seria subjetiva; em contraste, a ciência seria objetiva. Daí a arte focaria emoções (às tantas, irracionais) ao passo que a ciência focaria dados tão-só racionais. Na verdade, em vez de se considerarem estas esferas como pólos de atividade opostos, incumbe-nos abordá-las como manifestações diferenciadas provenientes de uma única fonte de criatividade humana. As ciências humanas e naturais, juntas, revelam que a expressão artística em conjunto com a experimentação coexistem e colaboram desde sempre na história cultural da nossa espécie. A ciência e a arte, juntas, têm evoluído e impulsionado o progresso cultural da espécie desde, por exemplo, as gravuras rupestres e o uso do fogo até à cerâmica. Com o advento da Revolução Industrial, implantou-se o modelo de especialização com vista à orientação do aluno para uma ou outra das duas esferas; daí a transformação de esferas correlatas em domínios separados e, por fim, o divórcio epistemológico entre estes dois domínios tendencialmente entrincheirados em universos disciplinares distintos. Consequentemente, cada universo obedece a uma lógica de especificidade disciplinar – à sua própria lei gravítica epistemológica – que agrava a clivagem entre as esferas inicialmente correlatas de arte e ciência. As duas esferas separaram-se no mapeamento académico do saber, doravante cristalizadas em domínios disciplinares especializados transmitidos, por sua vez, por peritos especializados nas respectivas áreas de criatividade. É esta práxis educacional exclusivista que, no nosso caso, nos levou, primeiro, a escolher a arte, o que nos afastou, por seu turno, da esfera correlata – em termos de criatividade – da ciência. Felizmente, a arte e a ciência do vidro abriram-nos um novo horizonte de aproximação a ambas as esferas; além disso, despertaram a nossa curiosidade científica. A vida de um artista e de um cientista enche-se de momentos de epifania: momentos que o levam a níveis de realização pessoal cada vez mais profundos. No nosso caso, tais momentos de revelação permitiram-nos abraçar vários projectos de índole científica: a produção de vidro, a análise das suas propriedades e a exploração de conceitos científicos a fim de resolver questões de ordem técnica que acompanham o processo de criação artística. Actualmente definimos a arte e a ciência como atividades correlatas de experimentação e criatividade: constituem processos de aproximação e comunicação, de reflexão e vivência que transcendem a perspectiva condicionada pela especialização disciplinar.

Ao viajar entre estes dois avatares da criatividade humana, explora-se nesta tese o valor e a necessidade de reintegração de ambos a nível educativo. Ao efectuar investigação de natureza transdisciplinar, o artista redescobre-se; reconhece a sua capacidade de estabelecer elos de intimidade entre a arte e a ciência. A tese patenteia, em conjunto com as obras em vidro da nossa autoria, as nossas incursões concomitantes no terreno aberto onde se cruzam arte e ciência: visa a expressão cada vez mais articulada do nosso modo de pensar, comunicar, experimentar e criar, doravante, a nível criativo, conceptual, experimental e pedagógico.

Palavras-chave: arte, ciência, educação, experimentação

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DICHOTOMY OF ART AND SCIENCE

> "Overemphasis on the competitive system and premature specialization on the ground of immediate usefulness kill the spirit on which all cultural life depends."
>
> -Albert Einstein

Education should be something that develops the potential of students, helping them to discover their abilities and empower them to find their own way in the world. But it seems that our current model of education that most of us are familiar with is indeed doing the opposite; stifling our individualities and killing our creativity. The education system that has been in place that was designed to meet the interests of industrial economies, in fact inculcates us with a very narrow view of intelligence and capacities. This, I believe, has led to the development of specialized education, institutions, and departments; hence nowadays art and science are more separated because of that intellectual specialization. True, as workers are trained or taught to do specific tasks, they are more productive by means of division of labor. Specialization makes it more effective to cope with the knowledge in a specific field, to efficiently organize the industry, to standardize the field, and by then improve the economy.

But in this generation, specialization is outmoded in our contemporary condition... One of the reasons is our world is changing so rapidly that what we were being taught in school by an education system designed decades ago will be irrelevant once we enter the workforce. The rote learning for specialization in that system is indeed stifling our creativity and critical thinking. With the constantly changing and exponentially growing knowledge, specialization as for the factory workers could not apply to this world already. In contrast, other human traits that technology struggles to replace, like critical thinking, curiosity, creativity and problem solving should be primary.

QUESTION IN EDUCATION

I remembered a math question in a school exam and that was the day I started to be ignored by the teachers because they thought I was problematic. The question was as simple as this…

"The oranges in the supermarket cost $3 each, and Peter has $12. How many oranges did Peter buy?"

I answered "he didn't buy any oranges.", and then I got a huge red "X" on my answer. After that I went to the staff office and argue with the teacher. In the end, I ended up crying in the office. To this day, I still think that my answer is correct. Without a doubt, the teachers would only expect every student to answer a simple math question in that case, but at the same time they were destroying personal initiative and creativity when they told the students to be out of the box in some other classes. In fact, the teacher should be facilitating to help the students to reach their personal progress and develop critical thinking. The school should not be a place that the teachers tell you what to think and all your duties are to write it down.

Being creative doesn't come with memorizing the information or knowing the model answers; it could probably come from thinking outside the box and challenging the questions.

In schools, there is not much room to accept any differentiation because everything has to be measurable. When its math, you have to calculate and no one will care if there can be any alternative answer or not. In class, our worth is judged only by our scores, and that score is the main or maybe the only standard for your capacities and what you are good at. We are forced to separate different subjects, and at the same time, be specialized in different area, like science, business or art. However, most of the educational system doesn't recognize the same mentality, same way of thinking and some of the same techniques underlie these separated subjects. Ironically, we are still under this specialization dominated education when robots can do a better job in specialized work than us. We, as human beings, prosper best with a broad curriculum that celebrates our various talents, not just a small range of us. If we can embrace independent thought, making mistakes and shape the students' own paths through education system, I think we could foster their creativity and uniqueness instead of creating robots.

The students who learn fast and succeed in the test are deemed "gifted" and the kids who take a little bit more time or thrive in different ways are marginalized for their lack in the "success" category. Maybe I was one of the latter ones and constantly defined as incapable of learning, especially in science and math. However, once I found the other side of myself in learning science, I realized what I gained was not only the knowledge, but also a healing of the wound from neglecting my capabilities. Now, I conceive of different disciplines (science and art) as different perspective of looking at the world. As inspired by Sir Ralph Waldo Emerson in *Nature*, nature is already in its forms and tendencies, describing its own design. We, as human, are observing and interpreting the essences (of nature); space, the air, the rover, the leaf.[1] And a work of art is an abstract or epitome of the world, the result or expression of nature, in miniature.[2]

[1] Ralph Waldo Emerson, 1836, p.7
[2] Ralph Waldo Emerson, 1836, p.29

OUR ENGINEERED NATURE

> "Have mountains, and waves, and skies, no significance but what we consciously give them, when we employ them as emblems of our thoughts?"[3]

"There is no logic to scientific discovery. Or, rather, that if there is, it is only the logic of everyday life." Collins and Pinch conclude in "*The Golem*"[4]. In other words, science, which is always related to objectivity, depends upon what we see and experience. The objectivity is the result of the work by humans, which is based on the experience, corresponding to subjectivity. Hence, the understanding and the view point in this thesis are extracted and translated from my experience and perception. Just as with scientists, an artist learns by individual experience and sees the world in his/her perspective. This is the nature of art making. From my personal experience and perception on art and science or any other domains, we can see the importance for growth, either myself or the world, is in fact from our individual story, experience and then go farther to our field or the stuff in nature.

Man, as the minister and interpreter of nature, does and understands as much as his observations on the order of nature, either with regard to things or the mind, permit him, and neither knows nor is capable of more.[5] Seeing the world with Emerson, all the facts in natural history taken by themselves, have no value, but are barren, like a single sex. But marry it to human history, and it is full of life.[6] We, as human beings, are constantly seeking to make connections to nature through our interpretations and our language. We created math, symbol and explanations nature, associated with "objects", forming the expression of particular meanings.

From what I understand, it's not easy for us to judge scientific claims by ourselves. And indeed, this is also true for most of the scientists outside of theory own specialties. Then why can they be so confident to accept the claims of other scientists? It's because the scientific knowledge is built by the consensus of the experts throughout the history of science. The knowledge and technology that we have nowadays are developed by the collective wisdom, the collective intelligence and the collective work of the people who put effort into it. In other words, our trust in science is actually the same as our basis in trust in the experience. Looking at Charles Darwin, one of the most famous naturalists in history, he collected beetles obsessively when he was a student in Cambridge by his own interest in nature. Before he published his theory of evolution, he went to a five-year voyage aboard HMS Beagle and collected plants, animals and fossils, took copious field notes without any clues of natural

[3] Ralph Waldo Emerson, 1836, p. 41
[4] Harry Collins & Trevor Pinch, 1998, p.140
[5] Francis Bacon, 1902, I
[6] Ralph Waldo Emerson, 1836, p. 35

selection theory. But that experience became the foundation and the evidence to develop his remarkable theory.

> "Every man's condition is a solution in hieroglyphic to those inquiries he would put. He acts it as life, before he apprehends it as truth."[7]

If science is just a way of knowing and understanding the natural world, I believe that no significant ethical issues arise in science because I presumed science as "objective". I have been told that science studies facts, employs objective methods, and produces knowledge and consensus. However, there is one of the human factors taken into account, ethics, which involves the study of values and triggers different opinion.

Seemingly, science and technology are supposed to minimize suffering, save the planet and look after future generations. However, they are constantly pitting our values against each other. One of the most controversial topics of science and technology would be the ethical questions of tweaking genes to shape future generations. As the revolutionary technology of genetic modifications- CRISPR has developed, it has bought up the issue of designer babies. Despite the fact that it condemns children to preventable suffering and death, and denies them the cure, the controlling of human evolution seems to make this technology into a taboo. Who determines which traits are good or bad? Do we risk eliminating unique and different people from society? Genetic modification is not the only difficult issues to be addressed when we talk about "doing" science.

We can understand the world better and even change it technologically, such as artificial intelligence and pet cloning. But, a pantheon of ethical questions have arisen from these developments, thus, social norms are forbidding certain practices or even ways of thinking. When science is not only a human endeavor towards knowing and "improving" the world, it makes our way of pursuing science even more subjective by applying human values.

[7] Ralph Waldo Emerson, 1836, p.6

THE GADGETS OF CREATION

> "Every property of matter is a school for the understanding, - its solidity or resistance, its inertia, its extension, its figure, its divisibility."[8]

Nature, in its ministry to man, is not only the material, but is also the process and the result. All the parts incessantly work into each other's hands for the profit of man.[9] Science provides us the language of communicating with the materials, the nature. Undoubtedly, in the process of making art and creating things, we are creating a dialogue with the materials from our hands and eyes to the behavior of the materials. At the same time, science creates another level of communication through which we can establish contact by data, math and analysis.

Materials are predominantly used for tools, weapons, utensils and for self-expression, such as for creating decorations or art. By understanding the science and engineering of materials, we are able to develop more sophisticated material and increase usage. With the collision of art making and science/technology, we are pushing the boundaries of art and creating new human experience. In other words, we generally invented and used more elaborate materials by raising the intimate connection with nature and its components.

After getting interested and digging deeper into science, a new way of looking at my materials opened up, and more possibilities for me to create my work were visible. Therefore, I ventured into scientific research and study, and carried out a project investigating in the basic composition of soda-lime-silicate glasses, which we commonly use in art practice and in the glass industry. I then studied the impact of contamination from crucibles in common glass melting processes (see Appendix p. 31-45). Perhaps it was a way of understanding the very basis of glass, the material that I always work with, or merely the self-edification through looking at the material in another perspective.

> "To the attentive eye, each moment of the year has its own beauty, and in the same field, it beholds, every hour, a picture which was never seen before, and which shall never be seen again."[10]

"How do we observe nature, and what is the proper analysis of our observation? These are initial questions for both painters and scientists."[11] We started with perceiving nature through the senses. For instance, painters "analyze" or "review" their experience and feeling to reproduce the visual images on

[8] Ralph Waldo Emerson, 1836, p.46
[9] Ralph Waldo Emerson, 1836, p.16
[10] Ralph Waldo Emerson, 1836, p.23
[11] Leonardo, da Vinci, 2008. p.102

the canvas. In that sense, humans are beings of intermediary understanding and demonstrate the magnificent view of the infinite works of nature.

The way of seeing nature through science, on the other hand, creates other “lens” to observe, see and read the world. Likewise Leonardo da Vinci observed physicians at work to learn the layers of muscle and bone structures in the body and applied them into his art. Another significant example would be the invention of glass which has allowed us to view the world in a different light and perspective. From the creation of glass to the development of stained glass, we have created a new type of glorious space bathed in light. Likewise, by manipulating the optical properties and changing the shape of glass, we are able to bend and sculpt the light accordingly for a new vision.

FINDING THE EQUILIBRIUM

"Manning the woodland beyond. But none of them owns the landscape."[12]

All of this has led me to think of science as an art form; if mathematics is the language of science, then each artwork is a language of art… And like art, scientific discoveries can also inspire a sense of awe… And the symmetries and inevitability of natural laws seem to be of a certain elegance. It is my conclusion that both are tightly interlocked fields of study worthy of our passion, and their agents worthy of admiration.

In art making, the process is always unpredictable, surprising and precarious, just as in conducting a scientific experiment… In the past, I was frightened of being wrong and I felt that mistakes are the worst thing we can make. But now I found that the very joy of failure and the promise of revelation and the discovery always come in the process and that is the value of learning from trial and error.

Modern education is typically grounded in the intellectual specialization, which an individual or field becomes ever more focus in one idea or investigation, as discussed in Chapter one. Hence, we are lacking in dynamic experience in our schools and universities today. In my experience I recognized the growth of understanding more often comes from opposition than from agreement, from questioning and trial and error. In the process of getting unexpected result or error, I felt the struggle of my viewpoint meet with the disagreement and rejection from my result. If we can take this opposition as something to question, to communicate, or to be fought against, then we can gain the opportunity to grow from a more profound understanding.

"It is the peculiar and perpetual error of human understanding to be more moved and excited by affirmatives than by negatives; whereas it ought duly and regularly to be impartial; nay in establishing any true axiom, the negative instance is the most powerful."[13], said in *Novum Organum* by Francis Bacon, and that seems to be the understanding of the basic logic of falsification developed by Karl Popper. Falsifiability means that it is possible, at least in principle, to design and execute a test that could prove the theory wrong.[14] We try to transcend our problems by testing, with a reliance on carefully structured experiments. Though this process of experimenting, we can consciously change the potential case of interest and then observe whether the outcome changes. And in the process, we are indeed trying to find a counterexample that disproves the idea. When we fail to find

[12] Ralph Waldo Emerson, 1836, p.11
[13] Francis Bacon, 1902, XLVI
[14] Karl popper, 2005, p. 57-73

counterexamples, the theory can be accepted as a useful practical guide to action and more reliable in practice. And after all, we can also refer to the idea of “trial and error”, the basic process of learning. Art making, at its core, involves the understanding of what and how inputs affect outputs, and thus building a model of the way things work. This kind of constructive friction that is generated by the process of trial-and-error helps us to think and build knowledge in a coherent fashion.

BEING A RENAISSANCE MAN

> "Imagination is more important than knowledge. For knowledge is limited, whereas imagination embraces the entire world, stimulation progress, giving birth to evolution."
>
> -Albert Einstein

Science, Art or any other forms of knowledge are just the labels for results, but creativity is the process before a product. Our "product" can be directed towards a label of art or scientific outcome, but we are simply being creative. As Warren Karp asked, "Is there really a difference between a mind contemplating the relationship of light and mass and a mind contemplating the relationship of light and shadow?"[15] The power of human creativity is everywhere, in the technologies we use every day, in the clothes we wear, in the music we listen, and basically any products we use. No matter art, science, technology or poem, they are all creations of human creativity. In the biography of Albert Einstein, Walter Isaacson says, "As a young student, he never did well with rote learning. And later, as a theorist, his success came not from the brute strength of his mental processing power but from his imagination and creativity. He could construct complex equations, but more important, he knew that math is the language nature uses to describe her wonders."[16] We should see creativity as a singular human capacity and process that can be used in multiple, maybe infinite ways.

> "The most beautiful thing we can experience is the mysterious. It is the source of all true art and science."
>
> -Albert Einstein

Great artists and great scientists have made creative or inventive leaps that resulted in ground-breaking innovation that have revolutionized our way of living and experiencing the world. Whereas a great work of art can reach deep within us and affect us so profoundly that it changes our perspective and how we feel about our personal realities, Science provides an understanding of a universal experience. Art provides a universal understanding of our experience.

All of this shows that we need to have dynamic exploration and understanding of different types of "knowing" and avoid restricting ourselves to one single type of knowledge. We have been through a period where art and science were separated significantly in education, even in the culture. With the

[15] Warren Karp. 7 March 2016, "Art and Science" OR "Art or Science"?, https://www.youtube.com/watch?v=WfpK8TZFldA&t=209s
[16] Walter Isaacson, 2007, p.7

quickly evolving society, it won't be practical to think that way anymore. The simple way to look at this is that science and art are just labels for the results but creativity is the process; the same as artists and scientists finding ways that "make sense" for an application. This is why we should blend art and science in the education.

"Light is the chaser away of darkness. Shade is the obstruction of light."[17] With different perspective, we see light and shade as art, science or any other division or subdivision. But in fact light and shade, like everything else, are all part of us, part of our continuum. If we erase the boundary or build the bridge between art and science, each one of them are just different manifestation and incarnations of human creativity. And that's what we have to reconcile in our minds how these things fit together.

Rather than saying learning art and science, more profoundly, I will say we should learn like a Renaissance man (or woman) or polymath. One of the most famous and prolific examples of polymaths in human history must be Leonardo da Vinci. "He was able to jump between many fields to make valuable contributions when they were still young sciences… he bridged the gap from one profession to another when it suited his curiosity and his insights."[18] And he said that "Principles for the development of a complete mind: study the science of art. Study the art of science. Develop your senses- especially learn how to see. Realize that everything connects to everything else."

Renaissance man, not only means the cultured man of the Renaissance, but also defined as a present-day man who has acquired profound knowledge or proficiency in more than one field (Dictionary.com). In Angela Cotellessa's research of the lived experiences of modern-day polymaths, she described them as individuals who have a wide breadth of knowledge and/or skills but who also have deep expertise in a number of disparate areas. They are open to broad experiences, can be a divergent thinker, and can solve problems in creative ways as a result[19].

Unfortunately, in this era, society doesn't really encourage the polymath. We are living and grew up in society dominated by the education based on specialization.[20] Most of us are required to choose an area or a field to focus on since high school. As Larisa mentioned, it seems like the deeper we go in one specialization, the more success we can possibly achieve. Without a doubt, there is an important

[17] Leonardo, da Vinci, 2008. p.122
[18] Roger Smith, Leonardo: Bridging the Gap, Research-Technology Management, 2014, 57:1, 58-59.
[19] Cotellessa, A. J. (2018). In Pursuit of Polymaths: Understanding Renaissance Persons of the 21 st Century (Doctoral dissertation, The George Washington University).
[20] Larisa Shavinina (2013). How to develop innovators? Innovation education for the gifted. Gifted Education International, 29(1), p. 54-68.

role of specialization in society; however, there are also drawbacks and limitations. As we keep narrowing our own fields, we develop tunnel vision and a partial and fragmented view. In the end, it might cause negative impacts to both us and our society due to the lack of creativity and innovation.

“We must focus education on principles, methods, and skills that will serve those (students) in learning and creating across many disciplines, multiple careers, and succeeding life stages”, concluded in Robert Root-Bernstein’s studies.[21]

[21] Root-Bernstein, R., & Root-Bernstein, M. (2017). People, passions, problems: The role of creative exemplars in teaching for creativity. In Creative contradictions in education (pp. 143-164). Springer, Cham.

Fig. 1 Poster of the exhibition *Pause*

Fig. 2 *Disfiguring*
Cast glass and steel stands
Size variable
2019

Fig. 2 *Disfiguring*
Cast glass and steel stands
Size variable
2019

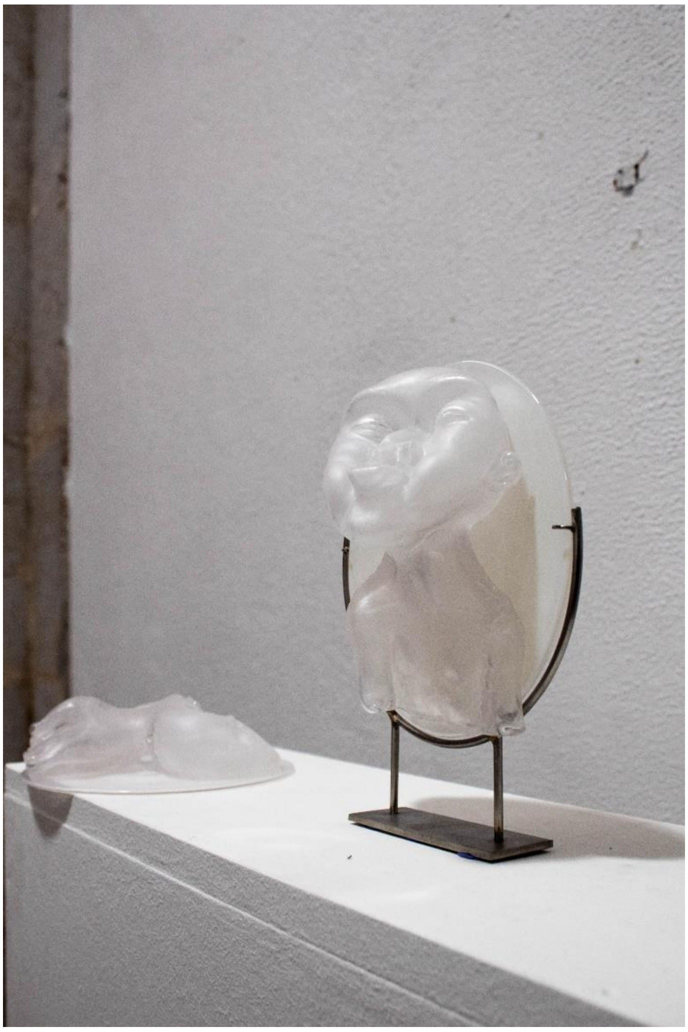

Fig. 3 *Failure #2*
Blown glass with stainless steel stand
Top right: (22x18x8) cm
Top left: (18x18x6) cm
2019

Fig. 4 *Failure #3*
Blown glass
(19x10x11) cm each
2019

Fig. 5 *Framed*
Cast glass and steel frame
(45x32.5x5) cm
2019

Fig. 6 *The Red Hood*
Stained glass
(60x42) cm
2019

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APPENDIX

Effect of MgO for CaO substitution in relation to the contamination from alumina crucibles in soda-lime-silicate glass

Objective: Soda-lime-silicate glasses play an important role in the glass industry with their applications spanning the range of ordinary and advanced products, including tableware, windows, display substrates, optical fibers and even for artmaking. In order to fundamentally understand and manufacture these materials, knowledge of its atomic structure is required for the examination of the properties of glasses with this composition, then study the impact of contamination from crucibles in common glass melting processes.

Making alumina crucible for producing glass samples (by slip casting)

Reagents and materials:
Distilled water- 1000cm^3, Carboxymethycellulose (CMC)- 3g, (from LC-Loja do ceramista.Lda), Dolapix CE64- 6cm^3 (Hans barnstorf), Magnesium oxide (MgO)- 0.5g (BDH laboratory reagents), Alumina CT 3000 SG- 1250g (Almatis), Hydrochloric acid, HCl (36.5-38%) (Scharlau), Plaster moulds (dry) (Alfamolde™ 7PL plaster from Formula Saint-Gobain).

Fig. 7 adding components while stirring.

The following steps were followed to obtain the alumina crucibles:
Step 1: Distilled water was poured in a container of 2L volume and started stirring by a laboratory stirrer.
Step 2: Gradually added the components with the order of CMC, Dolapix CE64, MgO and Alumina while stirring as shown in Fig 7.
Step 3: After adding all the components, the pH value was measured by universal indicator paper and check of the value is around pH= 9. If not, HCl is added to a maximum volume of 3cm^3.
Step 4: Continue stirring the slip that produced in step 1-3 for at least 1 more hour.
Step 5: After stirring, the slip is poured into the dry plaster moulds as shown in Fig 8.
Step 6: The water was absorbed gradually and the moulds must be filled up continually until the wall thickness is around 5mm (bigger crucibles need to have thicker walls).

Step 7: When the wall is thick enough, the slip in the moulds was poured out and reused.

Step 8: The crucibles were then kept inside the plaster moulds to dry for 1 day.

Fig. 8 Filling up the dry moulds with the slip produced in step 1-3.

Step 9: After the crucibles were completely dry, the crucibles were sintered in an electric furnace.

Step 10: Finally, the alumina crucibles produced were sintered at 1550°C in an electric furnace according to the following schedule:

Sample preparation

Table. 1 The composition for producing 10g samples.

	$MgaCO_3$	$CaCo_3$	Na_2CO_3	Na_2SO_4	SiO_2
$15CaO\text{-}15Na_2O\text{-}70SiO_2$	-	2.512g	2.580g	0.090g	7.037g
$5MgO\text{-}10CaO\text{-}15Na_2O\text{-}70SiO_2$	0.715g	1.697g	2.615g	0.091g	7.131g
$10MgO\text{-}5CaO\text{-}15Na_2O\text{-}70SiO_2$	1.449g	0.860g	2.650g	0.092g	7.228g
$15MgO\text{-}15Na_2O\text{-}70SiO_2$	2.203g	-	2.687g	0.093g	7.327g

Batches to produce 10g of glass were prepared using SiO_2 (from Honeywell), Na_2CO_3 (99.5% from Panreac), Na_2SO_4 (≥ 99.6% from Carlo Erba), $CaCO_3$ (99% from Scharlau) and $MgCO_3$ (from Riedel- de Haën). In all the compositions, 3 mol% of the total Na_2O was supplied using Na_2SO_4 as a refining agent. These batch components which are in powder form were mixed thoroughly using an agate mortar and pestle until a uniform mixture is obtained. The well mixed batch was partly transferred to an alumina crucible and heated to 1300°C in an electric furnace for 5mins. The temperature of the furnace was raised to 1550°C after transferring the remainder of the batch to crucible, and the melt was stirred after it reached 1550°C as shown in Fig. 9. Then, one more stirring was carried out and the melt stayed at 1550°C for 1 more hour for refining and homogenization to occur. Finally, the melt was quenched between two copper plate (Fig. 10).

Fig. 9 Stirring the batch for refining and homogenization

Fig. 10 The glass sample quenched between two copper plates.

Characterization & composition analysis

1. Composition analysis

The chemical composition of the glass samples was measured by PIXE (Particle-induced X-ray emission) at Instituto Superior Técnico - Campus Tecnológico e Nuclear. Through the application of an ion beam, PIXE measures the radiation emitted by electron state changes and identifies each element based on its unique emissions recorded as a spectral peak.

Table. 2
Analyzed glass compositions (mol%)/batched compositions were the xMgO-(15-x)CaO-12Na_2O-70SiO_2, where x=0,5,10 and 15. Glass codes are form CpMq, where p and q are batched molar contents of CaO and MgO respectively.

	Na_2O	CaO	Al_2O_3	MgO	SiO_2
C_0M_{15}	15.099	0.164	1.549	12.770	70.477
C_5M_{10}	14.764	4.266	3.285	8.903	68.782
$C_{10}M_5$	15.072	8.275	4.790	4.999	66.864
$C_{15}M_0$	14.481	12.648	6.956	-	65.915

Elemental analysis of the xMgO-(15-x)CaO-12Na_2O-70SiO_2 series is shown in Table. 5. Alumina is found as an impurity in all the glasses as expected. However, the amount of alumina contamination is determined by other oxides due to different reaction between them. By analyzing other properties of these samples, we are trying to observe the correlation of alumina and the alkaline earth oxide.

2. X-ray diffraction (XRD)

Fig. 11 shows the X-ray diffraction (XRD) pattern of the four compositions in the xMgO-(15-x)CaO-12Na_2O-70SiO_2 glass series. Powder X-ray diffraction patterns were collected using a Benchtop X-Ray Diffractometer RIGAKU. Each pattern was collected between 0 and 90° 2θ.

The samples were characterized to be amorphous with no features of crystallization by powder X-ray diffraction.

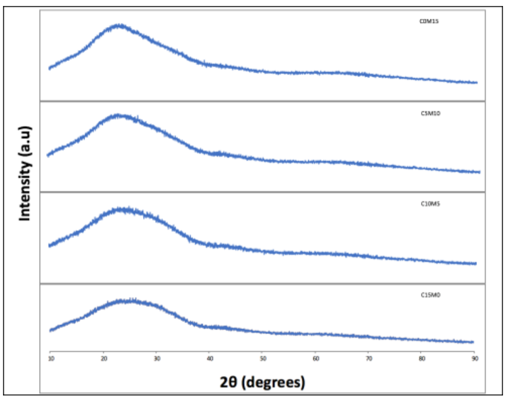

Fig. 11 XRD pattern of the xMgO-(15-x)CaO-12Na_2O-70SiO_2 glass series

3. Glass transition (Tg)

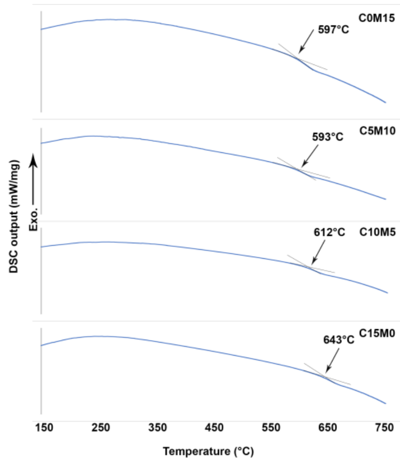

Fig. 12 DSC thermograms of the $xMgO-(15-x)CaO-12Na_2O-70SiO_2$ glass series

Differential scanning calorimeter (DSC) instrument (NETZSCH DSC 404F3) was used. The measurements were conducted in a purged nitrogen atmosphere (50mL/min) and the samples were placed in a platinum pan with an empty platinum pan as a reference. DSC thermograms recorded the rapidly quenched samples at a heating rate of 20K/min are shown in Fig. 12. The presence of glass transition endotherm confirms the glassy nature of the samples.

Physical properties

1. Density

Density (ρ) was measured using the Sartorius YDK03 density determination kit at room temperature (23°C) by the Archimedes method with absolute ethanol as the submersion fluid.

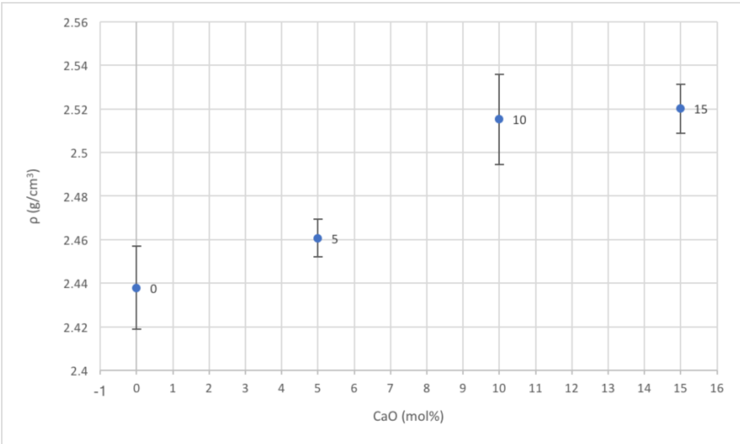

Fig. 13 Density as a function of the batched molar value of CaO

2. Vickers microhardness

Hardness was assessed using Vickers indentation. The polished surfaces were indented using a Zwick-Roell Indentec apparatus with 0.1 kgf load for 10s, enduring crack free indents. The average hardness comprises at least 6 indentation measures having a relative standard deviation less than 4%. The hardness was calculated using

$$H_v \approx \frac{1.854F}{d^2}$$

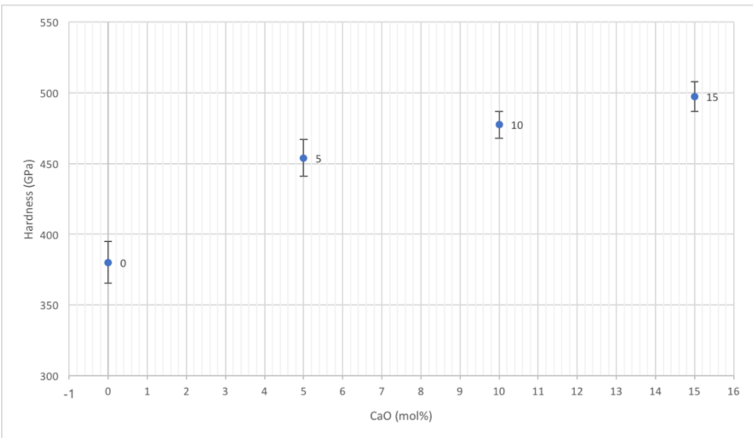

Fig. 14 Vickers microhardness (H_v) as a function of the batched molar ratio of CaO.

where F and d refer to the load (force) and the concave diagonal length respectively.

Raman Spectroscopy

Raman spectra were collected at room temperature using a Labram 300 Jobin Yvon spectrometer, equipped with a green laser operated with 532nm as the probing light source.

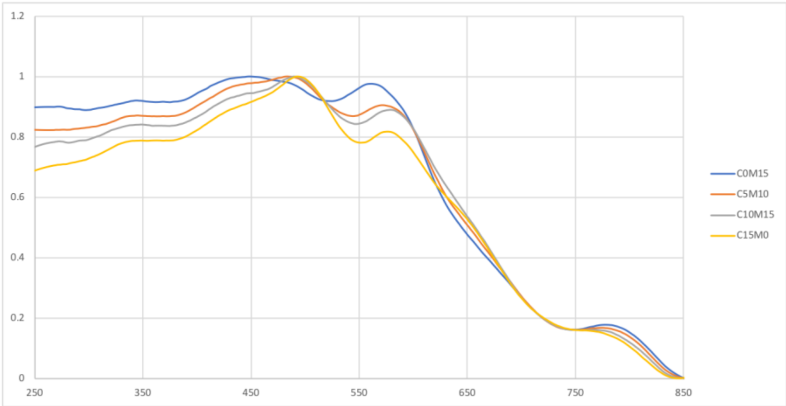

Fig. 15 Normalized Raman spectroscopy of the samples in 250-850nm region

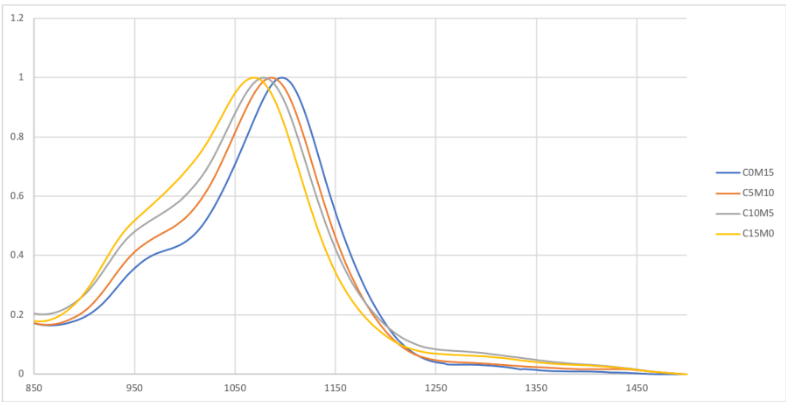

Fig. 16 Normalized Raman spectroscopy of the samples in 850-1500nm region

Conclusion: The presence of alumina in the crucibles allows us to infer that there we will find different levels of contamination in the commercial manufacturing processes. The interrelation of the alkaline earth oxides and alumina has a noticeable influence on the structural property on these glasses. From the glass composition (Table. 2), it is possible to conclude that there is an positive correlation between Al_2O_3 contamination and CaO content.